ELECTRIC ARC AND OXY-ACETYLENE WELDING

ELECTRIC ARC AND OXY-ACETYLENE WELDING

A PRACTICAL HANDBOOK FOR WORKS MANAGERS, WELDING OPERATORS AND STUDENTS

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PREFACE

THAT there should be a call for a new edition so quickly after the publication of the Second Edition, is an indication of the continued progress in methods of welding. There now seems to be a keener desire for operators to know something of the science underlying the processes than ever before, also designers of structures appreciate the wider knowledge which they are now able to obtain to assist them in the more accurate evaluation of a welded joint as compared to a riveted joint.

Further efforts are now being made in the direction of holding examinations for welders and supervisors. An Appendix has been added to this edition which covers the more recent developments, and in this is included the recent examination papers of the City and Guilds of London Institute. Acknowledgment is hereby made to this Institute for permission to reproduce their papers, and this also applies to the City Technical College, Liverpool. Thanks are accorded to the Acetylene Bureau, Messrs. Thorn & Hoddle, Ltd., Murex Welding Processes, Ltd., The Quasi-Arc Co. Ltd., and Messrs. Hoggett, Young & Co., for permission to use information supplied by them, respectively.

E. A. A.
A. G. W.

PREFACE TO SECOND EDITION

THE forecast given in the Preface to the First Edition has been more than amply fulfilled, as the progress made in the various forms of fusion welding during the last few years has been remarkable. The application of welding methods to the building up of large plate and bar structures to take the place of heavy and costly castings is a striking feature in the development of the various welding processes, and seems to indicate a still larger field of usefulness in the future.

In the present edition a new chapter has been added which deals with the training of welders, indicating the line of study and training which should be followed by those who desire to become efficient welders or supervisors. Also a large number of questions have been inserted at the end of the book for the benefit of those who wish to test their knowledge of the subject.

E. A. A.

PREFACE TO FIRST EDITION

The process of welding in its many forms has now developed into one of the most important and universal of all metallurgical processes. Its use is spreading out in every possible direction, and there seems to be no limit to the kind of work to which it can be applied. For this reason the very best thought and intelligence should be brought to bear upon experiment and investigation, so that the most reliable results may ultimately be obtained in practice.

The virtue of this book is that it not only gives the results of all kinds of tests and experiments, but that it offers many practical suggestions, which it is hoped will be of use both to the electric arc and oxy-acetylene welder.

Acknowledgment is made of the very great assistance rendered by Mr. A. G. Walker, Instructor of both Electric and Acetylene Welding at the Liverpool Municipal Technical School, in compiling the portions of the book that deal with practical welding. Also thanks are accorded to Messrs. Rylands Bros., Ltd., for permission to use the results of experiments carried out at their works.

E. A. A.

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ELECTRIC ARC AND OXY-ACETYLENE WELDING

CHAPTER I

METHODS OF METAL JOINTING

In considering the various methods of welding that are in vogue for the jointing of metals, it will, perhaps, not be out of place to make a comparison of the general methods that are in common use for the uniting of metals. These may be summarized as follows—

(1) Riveting and bolting.
(2) Grooving.
(3) Soldering.
(4) Brazing.
(5) Welding.

Riveted Joints. Of all the methods that are in use for jointing metals, it is probable that riveting (Fig. 1) is the oldest. Whilst it gives a very secure connection, unfortunately where articles are required to stand great pressure, this kind of joint in its simple form is very inefficient. The percentage strength of the best design of riveted joint depends upon several factors, such as whether the plates and rivets are of steel or iron, whether the holes are punched or drilled, accuracy of workmanship, etc. Generally speaking, a joint that is formed with a plate having drilled holes is somewhere about 8 per cent stronger than a joint made in which the holes have been punched in the plate. In addition to the extra strength obtained by having drilled holes, there is also more uniformity in the quality of joint, and less danger from the

plates being strained through holes which have to be drifted on account of being out of alignment.

To give some idea of the inevitable waste of material that takes place in the construction of articles with riveted joints, it is worth knowing that a single riveted joint has an efficiency of only about 55 per cent. In a double riveted joint this is raised to about 70 per cent, whilst in a treble riveted joint as much as 80 per cent or more may be attained.

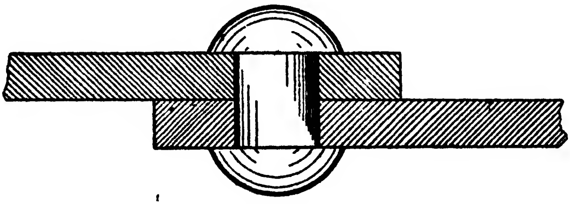


FIG. 1

From what has been said it will be seen that there has to be a considerably greater thickness of material used than would be otherwise necessary when riveted joints are adopted, this being specially so in the case of a single riveted joint. For when a vessel has to be constructed to withstand a certain pressure it is inevitable that it must be designed for the joint to be sufficiently strong to meet with the conditions required. So that where a single riveted lap join is used, on account of its strength only being about half that of the solid plate, it really means that plates of almost twice the required thickness have to be used.

Several devices, such as the thickening up of the edge of the plates which cover the riveted joint portion, have been devised to overcome the inherent comparative weakness of a riveted joint, but these have all been too costly to put into general use and have thus been abandoned.

Grooved Joints. It is not generally realized what a

valuable method of jointing is given by grooving (Fig. 2), but there is not the least doubt that the inventor, whoever he may be, of this method of connecting the edges of sheet metal together has conferred a very great boon upon the metal worker. If properly made, this kind of joint can even be water tight without the aid of solder, but if made in tinplate or other metal that can be soldered it represents one of the very few joints that is as strong as the sheet from which it is formed.

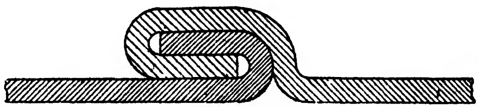


Fig. 2

Soldered Joints. These are made in almost any form of metal by using a flux such as chloride of zinc, and a solder composed of about equal parts of lead and tin. For many purposes this form of joint is exceedingly efficient.

Brazed Joints. These are similar to soldered joints, only that the solder material is a special form of brass, the flux usually being borax. To melt the brass and make the joint a much higher temperature than is necessary in soldering is required, the resulting joint being considerably stronger. A brazed joint in sheet metal is shown in Fig. 3.

Welding. There is a good deal of confusion as to the exact meaning of the term "welding." Some metal workers consider that it should only be applied when similar metals are welded together, but when a second metal is used as a uniting medium it ought to be referred to as soldering. Strictly speaking, the term "welding" can be used whenever metals either similar or dissimilar are intimately united together, either in their heated plastic condition or in a state of fusion. But for long generations the term "welding" has become so closely bound up with the uniting of pieces of iron in their heated

plastic condition that the term has come to be used in its more restrictive meaning. Perhaps it will be better to say that generally there are two kinds of welding, one known as "autogenous," in which a single metal is welded to itself, and the other as "heterogeneous," in which dissimilar metals are welded together or where a second metal is used as a uniting medium.

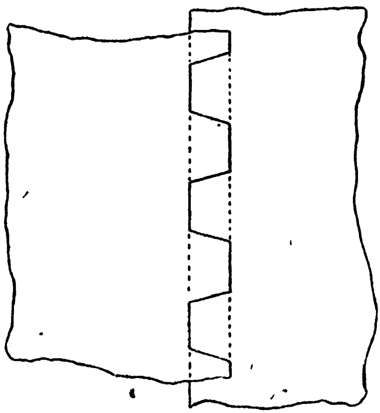


Fig. 3

Of recent years many new methods of welding have been introduced, and a description of these will follow after we have considered the ordinary blacksmith's weld.

Fire or Blacksmith's Weld. This is the most ancient method of auto-welding, its first use being entirely lost in antiquity. It can, however, be said with confidence that whenever early man made iron even in its crudest form, there are indications that he knew how to weld together the small pieces that were made in his furnace to build up those of larger dimensions which he required for fabricating into tools or other objects.

Many specimens of ancient ironwork have been discovered in India, such as beams, columns, tools, implements, etc. Perhaps the most remarkable of all is the wonderful wrought iron column (Fig. 4) which stands before the great gate of Delhi. These vast pieces of iron

FIG. 4

work were built up by welding the small lumps of crude iron, one on to the other, as shown in Fig. 5.

The dexterity which must have been displayed by these ancient workmen in building up large iron beams or columns by adding piece to piece was very remarkable, and the specimens of work left stand as memorials of their workmanship.

Whilst the blacksmith's weld is very common, it is not by any means always an efficient method of jointing, as

it is just one of those operations which brings in the personal element of the workman more than many others. No exact degree of efficiency can be fixed as to the strength of a blacksmith's weld, for whilst it is often said that the strength of a fire weld gives 80 per cent of the strength of the solid metal, actual testing shows that this is not by any means true. In some cases the strength of the weld when made by an experienced blacksmith may reach up

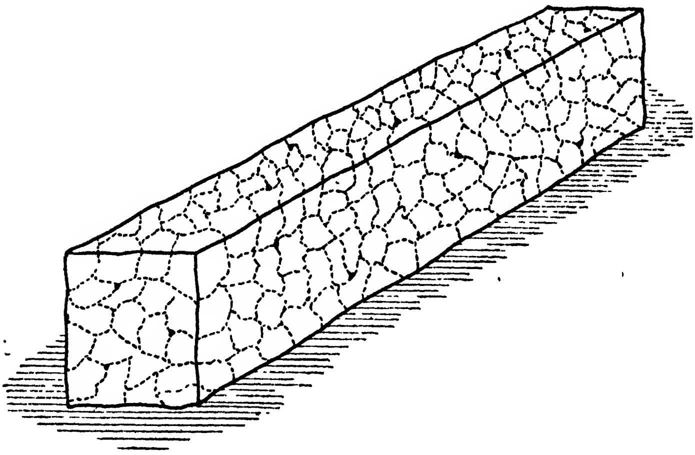


FIG. 5

to a strength equal to that of the solid bar, yet in other cases it may be anything down to as low as 30 per cent efficiency.

For good fire welding the ends of the bar should be heated to the right temperature, and it is certainly an advantage to use a flux of fine sand or a compound of equal proportions of well heated borax and salamoniac which will assist in removing any oxide from the surface of the metals to be joined. Any layer of oxide or slag which is bottled up in the weld is fatal to a strong joint, or any part

of the joint which is not welded inevitably leads to a reduction of strength.

Oxy-Acetylene Welding. During the last few years this method of welding has made enormous strides, and this is not to be wondered at when one considers the advantages of this particular method of jointing metals. The oxy-acetylene blow-pipe flame gives a very high temperature running up to between 6,000 and 7,000° F., this giving the temperature necessary to melt quickly any of the ordinary metals. In this system of welding, too, the blow-pipe flame if properly formed by the right mixture of gases gives certain products of combustion which act as reducing agents, and thus tend to keep the metal from being permeated with oxides, or allowing scale to form on the surface when the metal is in a molten state.

Oxy-Hydrogen Welding. The oxy-hydrogen blow-pipe has been in use in connection with lead burning and similar operations for a long time. For several reasons it cannot rank with the oxy-acetylene method or welding purposes. Apart from the fact that the temperature of the flame is lower than that of the oxy-acetylene blow-pipe, the product of combustion is a considerable drawback. In the burning of hydrogen, water vapour is always formed, this when it comes into contact with molten or hot iron causing the formation of oxide.

Oxy-Coal Gas Welding. The use of the oxy-coal gas welding is confined to low temperature work such as lead burning, brazing, etc., and therefore has a much more limited use than in the case of oxy-acetylene.

Oxy-Benz. and Oxy-Petrol Welding. A considerable amount of investigation in connection with the use of light mineral oils has been carried out on the Continent, but whilst under certain conditions these may give some particular advantages, as a rule they cannot compete with oxy-acetylene welding, at any rate so far as speed of execution is concerned.

Oxy-Water Gas Welding. This gas and several other gases of this order have been used with some degree of success for particular kinds of welding purposes, but up to the present, as compared with acetylene they do not warrant any great consideration except due to local conditions, where there may be some economic reason for the use of same.

Thermit Welding. Some years ago in this country, considerable interest was aroused by the application of thermit welding to the jointing of tramway rails and similar classes of work, but at the present time whilst it has its own sphere of usefulness it has nothing like the scope of acetylene and electric welding.

The process is very simple. A mixture of powdered aluminium and iron oxide is placed in a crucible, and then fired at the upper part. As aluminium has great affinity for oxygen it readily robs the oxide of iron of this element, combining with it to form oxide of aluminium. The molten iron trickles down through the heated mass and runs through a hole in the bottom of the crucible into a mould which is placed around the ends of the bar which required jointing together.

Electric Welding. There are really only two ways in which steel can be welded by the use of an electric current. One is known as the resistance method of welding where the electric current is used simply as a source of heat, the heat generated being due to the resistance set up at the joint of the metal, and the other is known as the Arc method of welding, the metal to be welded being either melted or vaporized in the electric arc.

Generally there are four kinds of resistance welding, viz.—butt welding, spot welding, seam welding, and contact welding.

Butt welding is the method adopted when the two ends of a rod, bar, tube, or wire are butted together and an electric current passed through the joint of sufficient

strength gradually to heat up same to the melting point of the metals, these being then squeezed together and welded.

Spot welding is used to take the place of riveting in iron sheets or thin plates. The sheets or plates are squeezed together over a small circular area in a grip. The electric current is then passed through the part held, and melts the portion of the sheet between the grip, bringing this up to a welding temperature and thus uniting same.

Seam welding is adopted for welding the two edges of a sheet together to form a tube or other article, and is carried out by passing an electric current through the seam from a pair of wheels which continually move along same, thus generating sufficient heat to weld the edges of the sheet together. This method of welding is what might be called a continuous method of spot welding.

Contact Welding. This method of welding is adopted in wire-work for reinforcing purposes, either for concrete buildings or road making. It is carried out in a machine through which a dozen or more wires are run longitudinally. Across these wires, at regular intervals, a thinner gauge wire is brought, which, after being pressed down into contact with the longitudinal wires, is welded to same by the passage of a current through the joints. The heat of the current instantly melts a little of the surface of each pair of wires, and these being under pressure are welded together.

Arc Welding. Arc welding of recent years has made very great strides, and its use is increasing day by day, both in its further application to wrought iron and mild steel, and also in the direction of cast iron and other metals. It is used both in connection with direct current and alternating current electricity. First introduced as the carbon arc method and later and more commonly as the metallic arc in which the wire feeding material is used as an electrode. The metallic electrode itself is usually coated with some

form of covering or flux, one of the objects of this being to protect the molten metal from becoming oxidized as it is deposited on the joint.

In Fig. 6 an electrically welded lap joint is shown, this being of the type used for the shell plates of large ships. The shaded filleted parts are those filled in by the deposition of the wire electrode. In Fig. 7 a similarly welded butt joint is shown, this being used where an unbroken plate

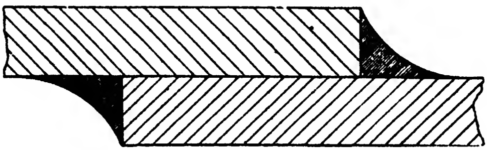


FIG. 6

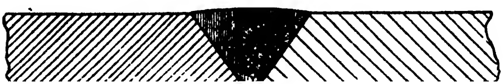


FIG. 7

surface is required. The strength of the lap joint is usually equal to that of the plate; in butt welds, however, the strength of the joint, except it is very carefully made, rarely equals that of the solid plate.

Cyc-Arc Welding. This is a method of welding which may be said to be a combination of the resistance and arc welding, and is applied particularly to the welding of studs or bars on to a mass of metal.

The operation of welding in this case is very simple, being practically automatic, and is carried out in quite a mechanical manner.

Hyding or Copper Welding. This is a very ingenious method of welding iron or steel plates, bars, etc., together by the insertion of a very thin film of copper, the metals

being raised to the required welding temperature in an atmosphere of hydrogen which has the remarkable property of enabling the copper intimately to unite with the iron or steel, thus forming a most effective joint. It is difficult to say what may be the result of this method of welding copper and steel together, but it certainly has very interesting possibilities.

The Object of Welding Processes. In dealing with all the various methods that are now in vogue for the welding of metals it should be borne in mind that the object of the particular process is to obtain such a temperature at the point of welding so as efficiently to fuse the metal, and at the same time to protect it from any external influences that will damage its qualities.

With the exception of the blacksmith's weld, nearly every other process is one of simple fusion or melting of the metals, and, indeed, may almost be referred to as that of casting. Remembrance of this fact should lead an operator to appreciate the difference between the physical properties of the metal before and after welding. It should, therefore, be clearly understood that the properties engendered in a metal by rolling, hammering, and drawing, are quite removed by fusion, and that it is extremely difficult to get these properties back again in a welded joint without the most careful treatment, and the application of proper safeguards in the carrying out of the process.

CHAPTER II

ELECTRIC ARC WELDING

ELECTRIC arc welding, it may be said, is only in its infant stage, but it is daily coming into greater prominence, and there are hardly any limits to its application to general engineering repairs, structural engineering, ship-building, etc.

During the Great War and the resulting enforced economy in the use of metals, much was achieved in giving electric welding greater scope for its usefulness than would have been the case under normal conditions.

To carry out efficiently a welding job by the arc method is not so simple as would appear to the casual observer, as he notices the ease with which a good welding operator proceeds with his work.

The essential points to be remembered to produce good welds, perhaps, can best be summarized as follows—

(1) The skill of the operator.
(2) The efficiency of the machine.
(3) The material to be welded.
(4) The electrode or feed wire material.
(5) The electrode coating or flux.

All kinds of difficulties will be met with daily in carrying out welding operations, but all these it will be found can generally be classified under one or more of the above headings. By the exercise of careful thought and with knowledge which it is hoped will be gained from the following chapters, the operator should be able to overcome any of the difficulties that are usually encountered.

In the progress of arc welding the following are some of the processes that have been successfully tried—

Benardos and Olzewski Process. This system, which

was patented in Great Britain in 1885, covered both for the jointing and coating of metals. The Benardos specification also mentions the use of metallic electrodes surrounded with carbon. It covered also for an apparatus called an electric solderer with two carbons side by side and a magnet to deflect the flame to the object under operation. The work is positive to the carbon electrode, therefore no deposit can take place from the carbon to the work. The current is direct, of about 90 volts and 250 to 500 amps., according to the thickness of metal.

Heaton and Slavianoff. Thomas T. Heaton, of Uxbridge, in 1893, suggested the use of a mild steel electrode, and it was tried unsuccessfully. It is rather unfortunate that this experiment was not carried further, as we now know it was potent with great possibilities. In 1895 Slavianoff introduced a metallic electrode to take the place of carbon, but whilst it was used to some extent in America, its application made no headway in this country.

Kjellberg. In 1907 Oscar Kjellberg, of Gothenburg, introduced into England a metallic electrode to replace carbon. He made the work negative to the electrode, as it was considered the natural tendency would be to deposit the metal of the positive electrode on to the work. This system, which is now the common one, is largely and successfully used. The metal of the electrode is fused into the joint and then hammered. The metallic electrode is coated with a slag flux, the main object of which is to prevent oxidation.

Zerener Process. Dr. Zerener, of Berlin, in 1890 introduced into Great Britain a system of two carbons and a magnetic deflector, which was somewhat of the same kind as the Benardos system.

The Strohmenger System. This is a process in which a metallic electrode is used as in the Kjellberg process. It may be said that this invention at once raised the quality of arc welding to a high level. Mr. Arthur Strohmenger

has brought out various methods of covered metallic electrodes with fusible insulating coatings, the coatings being of such a nature as to protect constituents that are usually burnt out of the metal in welding, and so reduce their loss. With some electrodes a very fine aluminium wire is incorporated under the coating. Blue asbestos yarn is especially preferred as a coating for the electrode for welding iron or mild steel, as it forms a reducing flux, and it may be smeared with sodium silicate or other substance to vary the fusing temperature of the yarn.

The metallic electrode is positive to the work, and in fusing is deposited upon it. The coating of the electrode when melted forms a vitreous slag, which covers the weld and which flakes off or is chipped away when cooled.

Of recent years there have been many other inventions in connection with electric apparatus to control the arc, and also for electrode material or coverings for same.

Advantages of the Electric Arc Process

Ship-building and Structural Steel Work. After the brief statement that has been made with regard to the various inventions in connection with arc welding, it may be said that generally electric arc welding has many advantages for certain classes of work over other processes. Not only has it been successfully adapted to the ship-building and repairing industry, but it is being more and more used in connection with steel structural work of modern buildings.

Reinforced Concrete Framework. Reinforced concrete framework can also be secured permanently with this process, and by this means any doubt removed as to the framework being moved out of position whilst the filling in of the concrete proceeds.

Tramway Lines and Points. Tramway tracks are now being reinforced and the joints, with fish plates, made secure, thus doing away with the possibility of slack joints

fuse wire, as too heavy a wire may cause serious damage to the generator.

It is also useful to have terminals on the fuse board so that a motor grinder can be switched on if necessary, as a good electrical grinding machine is essential to the proper finishing of work in a welding shop. A portable light is often very handy for the examination and preparing of work, and for this purpose one of the terminals may be used.

Cables. Flexible cables should be used for the electrode holder on account of their ease in movement and the greater facility with which the operator can get a fine adjustment of the arc than with the ordinary stiff or heavy cable.

Joints of cables should always be secured firmly by bolts, as any slack joints may cause a leakage of the current or bad contact, with resultant sparking which may result in a fire.

If the work to be welded is bulky it is always advisable to connect the cable firmly to the work, so as to avoid any small fusion spots due to bad contact which may spoil the machine surface.

Welding Screen. A useful screen (Fig. 12) can be made of three-ply wood about 18 ins. by 12 ins. with handle attached. A hole should be cut in the screen and recessed around for the reception of the glasses. These should be of three kinds—(1) Green next to the face; (2) Dark ruby in the middle; (3) Clear glass outside to stop the splashes of molten metal from the weld destroying the tinted glasses.

Each operator should endeavour to get the shades or tints best suited to his particular sight. The arc should not be looked at with the naked eye, and when at work the operator should see that the light from the arc does not glare into the eyes of fellow-workmen. It is also important that on part of the bare skin, either hands or

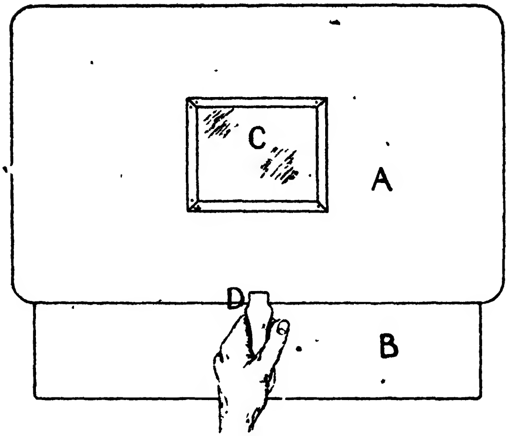


Fig. 12.—Welding Screen of 3-ply Wood

A = 18″ × 12″ 3-ply wood.
B = Piece of leather to protect the hand from rays.
C = Tinted glasses inside.
D = Wood handle.

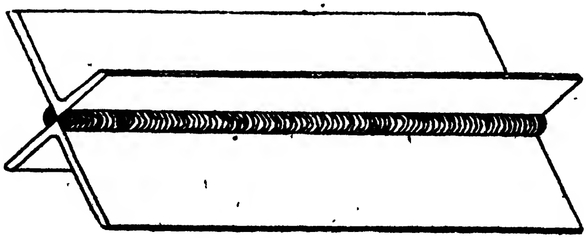


Fig. 13.—Vee Block of Angle Iron

arms, should be exposed to the rays from the arc, and this can easily be avoided by the use of suitable leather gauntlets.

Chipping Hammers and Wire Brushes are also part of the equipment, and must be freely used as required. When one layer or run has been made and cooled down a good scaling and brushing must then be done to remove the slag on the surface before another run is made, as bottled-in slag of appreciable quantities is deleterious to the weld.

Welding Table, Vee Blocks, Clamps, etc. A good welding table can be made from a cast iron plate that has a number of holes in it through which bolts are passed that enable the work to be held down. Vee blocks of various sizes are made in a simple manner by cutting off lengths of angle iron and welding the heels of two together, so that when looking at the end they form a cross (Fig. 13). Where round bars or broken rivets are to be repaired it will be an advantage to have a Vee block of the above type welded to a piece of channel iron which can then be fitted over the top of a trestle and will thus give a safe support for jobs of the above description.

Tool clamps are useful in the equipment for fastening broken portions in position until they are secured by welding. These are quite easy to make (Fig. 14).

A welding shop should also contain a blacksmith's hearth, as it will be found useful in a hundred and one ways.

For carrying out certain classes of jobs a pre-heating stove should be used. There are various kinds, but perhaps one heated by gas and compressed air will be as convenient in use as any other. In welding, the electric arc gives only a very local heat, and as there are many jobs, which, if to be successfully carried out require to be heated all over, it is essential that some method of pre-heating must be adopted. The stove, if made by the welder, should be

of such a character that the work can be easily manipulated. It is advisable to have hinged doors for top and front. The inside should be lined with firebrick slabs to retain the

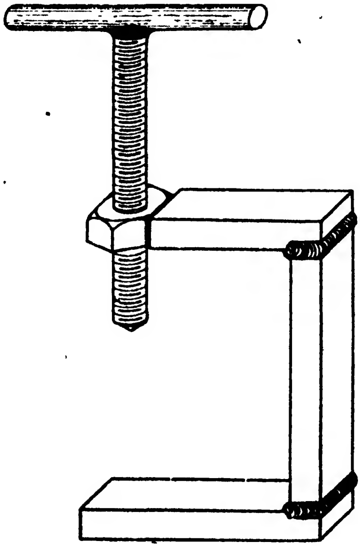


FIG. 14.—WELDING GRAB CONSTRUCTED BY ELECTRIC WELDING

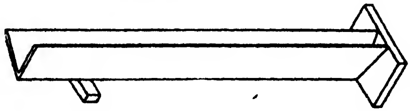
Can be made all sizes. A nut welded on the end for screw.

heat, and care should be taken that there is an ample supply of gas.

Various lengths of studding and plates should also form part of the equipment for properly securing work.

Flux Troughs. If the welder requires to flux coat his own wire electrodes, a simple trough (Fig. 15) can be

made out of 2-in. angle iron, about 15 ins. long with supports on bottom and one end stopped by welding a



FLUX BATH

FIG. 15

piece of plate to angle iron. The flux can then be mixed in this trough and the electrodes coated by rolling in the same, afterwards standing them on one side to dry.

A simple method of obtaining a coat of even thickness is to pass the electrode through a conical hole in an iron plate, the small end of the hole being slightly larger in diameter than the wire.

Tongs will also be required for handling hot work, and an anvil is a useful tool to have in the workshop.

A stand for storing tools, gear, etc., can be made in a simple manner by having four pipes or round iron bars for the uprights, with $\frac{1}{8}$ in. plate to form three or four shelves as required, these, of course, being welded together as shown in Fig. 16.

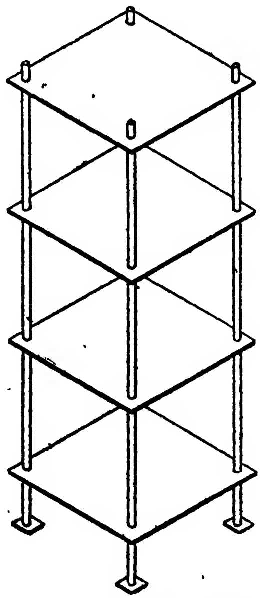


FIG. 16.—USEFUL STAND FOR WELDING SHOP

Portable Plants. Many are the styles and makes of portable plants, both for direct and

alternating current. A simple set consists of a petrol engine coupled to a dynamo which has a capacity of 200 amps. at 100 volts, with balancing resistance, welding resistance, and solenoid or magnetic cut-out on switchboard complete.

Where an engine is used for driving a dynamo a solenoid is used. This automatically cuts from the welding resistance to the balancing resistance and allows the engine to run with a steady load. Without a regulating device, when the welding load is taken off the engine it would race and damage might result.

There are many advantages with a portable plant, but its greatest feature, of course, is that it can be taken to any stationary job and welding repairs carried out on site.

Where alternating current is used it is necessary to have a special transformer for regulating and controlling the arc, the rest of the equipment being the same as previously explained.

CHAPTER IV

PREPARATION OF JOINTS FOR ARC WELDING

THE preparation of the work for welding is an exceedingly important part of the whole process. The operator should get into the habit of visualizing what is likely to happen to the material of a job in passing through the whole process of heating up, welding, and cooling, and to base the preparation of his work upon intelligent foresight.

The local heat of the electric arc is more intense than in other welding processes, and the speed at which metal can be deposited is also more rapid than is the case with gas welding. Details such as these and others must be taken into consideration when planning out the work to be welded In any case, very much depends upon the wisdom and intelligent foresight of the operator as to whether the weld will be a success or a failure.

A summary of the factors that go to the making of a good weld will be as follows—

(1) The operator should be confident in himself through suitable training and practice.

(2) The welding machine should be of the best manufacture with all suitable adjustments to give the operator full scope for the exercising of his judgment.

(3) Care should be taken that the Veeing of the joint is correctly done so that proper penetration can be obtained. The surface along the Vee should also be clean, so that no impurities may get mixed with the deposited metal.

(4) The electrodes used should be the best that can be procured, and in every way suitable for the carrying out of the job.

(5) As the flux coat on the electrode plays a most important part in the welding operation, it is advisable to use the best that can be obtained for the purpose.

As metals expand when heated and contract when cooling, care must be taken to allow for both of these conditions, so as to leave the job when cold in an unstrained state. No very definite rules in this respect can be given, as it is better that each particular job should have careful consideration, and the work prepared and carried out accordingly.

Plates thinner than $\frac{1}{8}$ in. need not be Vee'd, but in welding should be left slightly open at the joint to allow for penetration.

For heavy work the need for preparation is greater, and lifting tackle should always be at hand so that once the work is commenced there will be no stoppage on account of work requiring adjustment.

Types of Joints. The various methods of connecting plates together for electric arc welding are shown on Figs. 17, 18, and 19.

No. 1 is of plates $\frac{1}{8}$ in. in thickness and less, in which the ends of the plates are left slightly open so as to allow for proper penetration.

No. 2 shows the single Vee suitable for plates from $\frac{1}{8}$ in. but not exceeding $\frac{3}{8}$ in. in thickness.

No. 3 shows the double Vee for plates thicker than $\frac{3}{8}$ in. For mild steel the quickest way to prepare this kind of joint is to grind the Vees on the emery wheel, but in the case of malleable cast iron or cast iron the best way is to mark off the Vee and nick down with a hack-saw at intervals of $\frac{3}{16}$ in., then with a sharp chisel cut these away to the correct depth. This will save a large amount of chipping or grinding. It need hardly be said that the double Vee can only be used when the joint can be welded at both sides.

Nos. 4 and *4a* show the preparation of a joint for welding a cracked plate. Where possible the joint can be machined out or drilled as is most convenient, the point of the drill just penetrating the bottom of the crack, the division pieces

in between being removed with a cross cut chisel. This method is particularly applicable to cast iron work, and especially so if there is any danger of the crack extending.

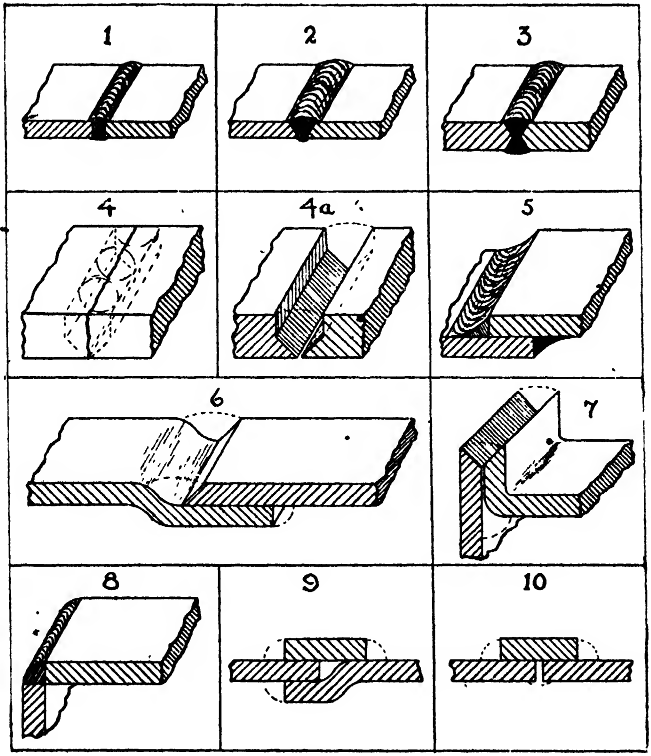


FIG. 17

No. 5 shows the simple lap joint upon which no preparation is needed, the end of one plate being welded on to the flat of the other as shown in the sketch. In connection with this joint great care should be taken that the plate is not thinned by too much fusion at the edge of the filling,

as this may bring about nicking and cause considerable weakening of the plate.

No. 6 is a joggled over-lap joint which is used when it is necessary to have one side of the joint perfectly flush with the plate surface. It will be noticed that the Vee on the top of the plate is formed by chamfering the edge of one plate and the incline formed by the joggling of the other.

No. 7 is a joint which can be used especially in connection with tank work. This joint can either be welded on the outer edges alone, or can be welded, if required, and is get-at-able, on the inside also.

No. 8 shows a simple method of forming a 90° Vee cornered joint without any mechanical preparation. This makes an exceedingly good and simple connection for tank construction or the making up of boxes. For the accurate making of this joint it will be necessary to have a knee plate or some other method for holding the plates in the correct position.

No. 9 shows the construction of a joggled joint with cover strap. This method of jointing gives no increased strength above that shown in No. 6; its chief advantage, however, is that it adds considerable stiffness to the plate, and can be employed in connection with welded ship construction.

No. 10 is an ordinary butt and strap joint, which can be still further stiffened by making a 60° Vee where the plates butt together. Whilst it is as strong as No. 9 it will not, of course, be quite as stiff.

A stiffer joint than both Nos. 9 and 10 is shown by No. 11. Whilst it will be necessary to weld the two plates together at the Vee there will be no need to weld completely the angle iron along its whole length, but only to tack same at intervals of about 4 ins. to 6 ins.

No. 12 shows a method of securing an angle bar to a plate to form a Tee section in case it is impossible to obtain

the required size of Tee iron to carry out some particular job.

No. 13 shows another method of forming a Tee section.

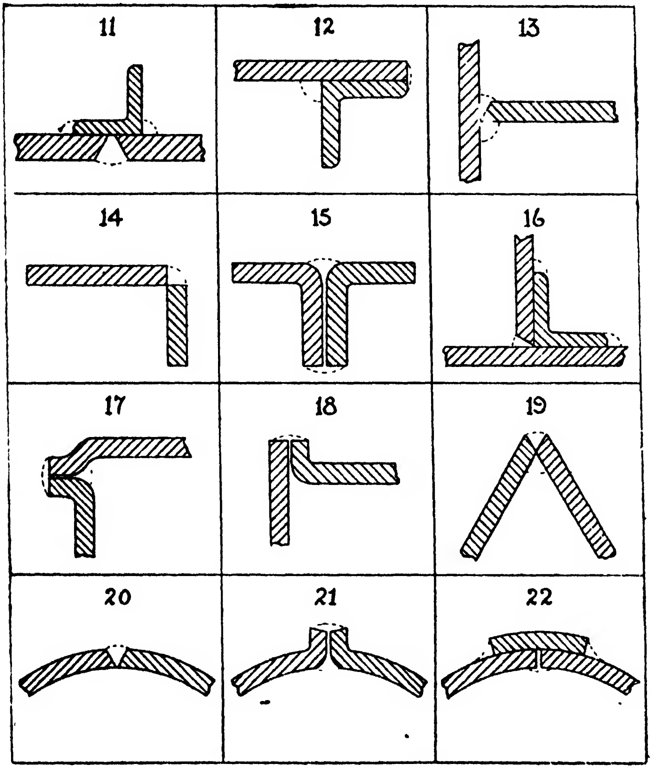


FIG. 18

No. 14 shows a method of joining two flats to form an angle.

No. 15 shows a method of jointing two angles to form a Tee.

No. 16 is a similar method of jointing to No. 13, but reinforced with an angle bar.

Nos. 17 and 18 show methods that can, respectively, be adopted for jointing the tops and the bottoms of closed tanks.

No. 19 shows how plates can be welded together at any desired angle. This joint possesses considerable strength and stiffness if welded at both sides.

No. 20 shows an ordinary 60° Vee for the side seam of a tank. Whilst No. 21 shows a flanged seam for tank welding to give great strength.

No. 22 shows a butt seam for a cylindrical tank together with curved cover plate.

No. 23 shows a joint for a round bar. In preparing the ends of the bars they must be ground with chisel edges and on no account ground with conical or centre punch ends, as with the latter great difficulty will be experienced in depositing the metal, this running around the joint and causing adhesion instead of the metal being welded. It is, therefore, essential that round solid bars should be prepared as shown in the sketch.

No. 24 shows the joint preparation for a pipe or bush. In this the Vee should be about 60° up to $\frac{3}{4}$ in. thick, but above that thickness the method adopted for joint No. 4 can be used with advantage.

No. 25 shows the method of welding that can be adopted in butting together the ends of two pieces of pipe.

No. 26 shows how a branch pipe can be welded on to a main pipe to form the Tee, the joint in this being reinforced according to the pressure the pipe is required to stand.

No. 27 gives details of the methods that can be followed for the preparation of two pieces of pipe to form a right-angle elbow. This joint, again, can be reinforced as required for purposes of extra strength.

No. 28 shows the method of obtaining any angle for a bend by one saw cut according to the required angle.

Thus, if a bend is required to be 130° as shown in No. 29, then it will be necessary to saw the pipe off at an angle of one half the 130°, that is 65°, as shown in No. 28.

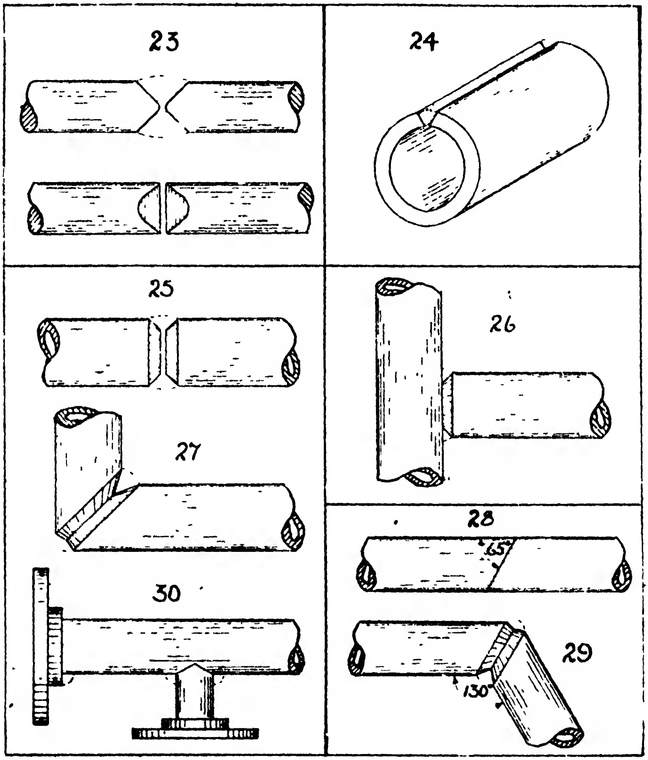


FIG. 19

Then in jointing simply reverse one of the arms, so bringing the two 65° angles together to make up the bend of 130°.

No. 30 shows the way in which flanges of any thickness can be welded on to the ends of pipes as required.

Care in Setting Up. In welding it is not an easy thing to produce work that will be absolutely correct both in shape and to bevel, and it is often a good plan to set the work up carefully and tack it every few inches before proceeding to weld the seams along continuously.

Where the longitudinal seam of a cylindrical article is to be welded it is advisable to drive a wedge into the joint at the farthest end and commence welding at the other end. This opening of the joint at the farthest point will allow for contraction without any distortion if the wedge be removed at the right moment.

Another plan in the case of heavy work is to get a helper to keep the joint open with a bar as the welding proceeds along, thus putting the edge of the plate in tension, which will equalize the strain set up by contraction.

Travel of the Electric Arc for Various Kinds of Work

As Illustrated by Figs. 20 and 21

A. Half-circular movement which can be used on thin material, also for filling holes in thin metal. The speed of travel should be a little greater than that for metals of extra thickness.

B and C. Circular movement. Great care is needed in this method to obviate slag inclusions. If heavily coated electrodes are used this method is not advisable on account of possible slag inclusions.

D. A good gyratory movement, which gives economical results. This is a movement that should be adopted when heavily coated rods are used, so that the slag may be kept apart from the molten metal.

E. Three sides of a square movement is a very good one for saving the edges of the parent metal from being unduly melted away. It is also a good movement for welding cast iron with the special coated rods, and would give the

required movement to puddle the added metal, which is essential for good welding.

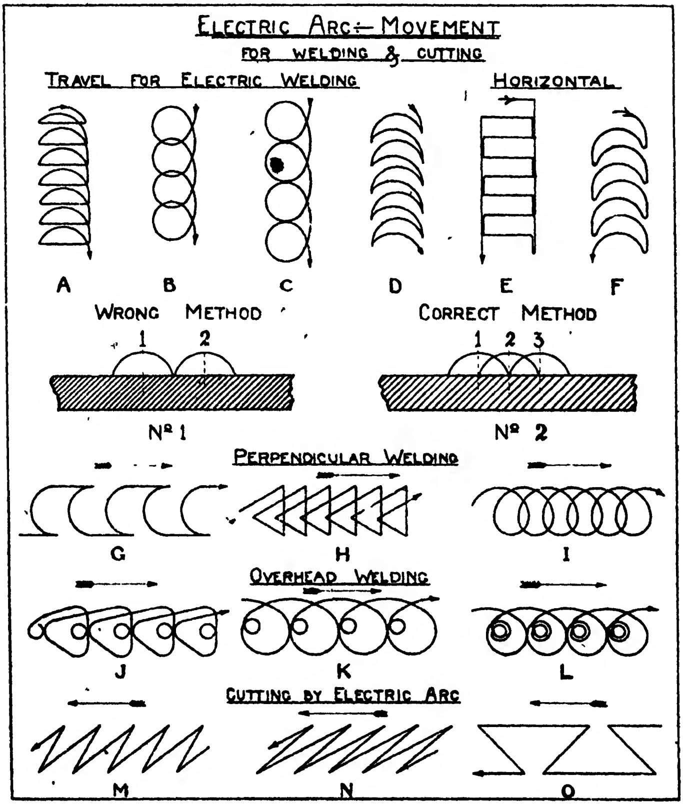


FIG. 20

F. Half-circular movement with greater travel than *D*. This is also a good movement which it is advisable to adopt on some jobs. The travel is economical, but care must be taken to obtain perfect jointing of the metal.

This travel motion is also very good for filling up the Vee, and the extended sides, causing these to have good penetration.

Note.—All diagrams *A*, *B*, *C*, *D*, *E*, *F*, are somewhat exaggerated so as to clearly define the exact movement of travel.

No. 1 and No. 2 show sectional views of the wrong and correct methods of depositing metal. When work has to be reclaimed and afterwards machined on the surface it is essential that the correct method should be adopted so as to obtain the best results.

No. 1 shows two runs with the wrong method. A careful study of the sketch will show that between the two runs a Vee is formed, and unless this is filled correctly, a very bad finish will result. A third run could be made at this Vee, but it would not be economical as it entails an unnecessary amount of labour to remove the surplus metal.

No. 2 is the correct method to adopt. Run No. 1 is first deposited, the edge of No. 1 being the centre—as shown—for No. 2 run. The edge of No. 2 then being the centre for No. 3, and so on, until the full width is made up. This joint will machine to a nice surface, leaving no unnecessary surplus metal to remove. A careful study of the diagrams will make clear the main points.

The welded portion must be hammered—if on mild steel—to close up pin holes, and also to engender in the metal a suitable grain size to give toughness.

Perpendicular Line of Welding. Sometimes the operator will be called upon to build the sides of an object that is worn or pitted, and choice of motions at his command will enable him to find which will be most suitable for the particular job. A good plan (Fig. 20) is to commence with the bottom run first, then the second run, and so on until the part has been built up. The direction of travel can be chosen from *G*, *H*, or *I*.

If only a small amount of deposited metal is required

the travel *G* should be adopted; but if a large amount is needed then *H* or *I* would be more suitable.

The important point is to not only have the correct current, but also to let the flow of the depositing metal regulate the speed of travel. Regularity in the movement is also essential so that the metal may be deposited evenly, and also that the finished work may have a good appearance. Practice is important for this position of welding if the highest results are to be obtained.

Overhead Welding. This requires the greatest amount of skill. Gravity has to be overcome, and this makes the process much longer because the metal cannot be projected overhead as quickly as if welding downwards. The current required is a little higher than ordinarily used. Special electrodes are sold for this method, but if any difficulty is found in procuring these special rods the following may assist in doing overhead work. The face must be well protected, also the hands, and a covering to safeguard the clothing while working in this awkward position. The main point to follow is to have the greatest heat at the centre of the Vee, then move the point of the electrode to the sides of the Vee—as shown on the diagrams for overhead welding.

Many are the movements that can be used, but the three shown on diagrams will answer the purpose.

J shows the heat first in the centre, and round one side, then back to the centre before the movement is made to the opposite side of the Vee. If that is not sufficient,

K should be adopted, and if then failing to obtain the desired result it would be advisable to adopt method

L with more heat in the centre than the sides.

Plenty of practice is essential to achieve success. Determination to master the art of overhead work is necessary, because at the first attempt the operator may feel a little

disheartened, but with practice the operation will become easier each time attempted.

The point of the electrode should be almost 90° to the work, and can then be further adjusted to an angle that will suit the progress of the work. It should be kept in mind that the deposited metal will follow the arc, and this will help towards making a successful job.

Cutting with the Arc is a melting process, and the current required is much higher than for welding.

A coated rod is preferable because this increases the temperature of the arc by the incandescent flame from the flux in addition to the arc at the gap, or space between the rod and work. The travel is usually the opposite way to that for oxy-acetylene cutting, and also in the opposite direction to that of electric arc welding. The operator should start from the nearest point, and work away from himself, this movement giving the best results.

Diagrams *M*, *N*, *O* show three different motions of the electrode for cutting. As this is a melting process it can also be applied to cast iron, brass, bronze, and material that it is impossible to cut by the oxy process. It should only be applied in extreme cases, because of the high expense and the tendency to burn the material which is cut. (*See* Chapter XIII on Cutting by the Arc and Gases.) The zig-zag motion should be applied, and can be used as shown on diagrams *M*, *N*, or *O* (Fig. 20), according to size of cut and thickness of material. The operator need not be bound down to any particular method of travel, as those shown are only intended as a guide to assist the inexperienced operators. Usually each operator has a style of manipulation of his own, found by practice, which may differ greatly from the ones given, hence the movements indicated are only intended to guide those who are in search of information, and who have not had the required practical experience to obtain the most satisfactory results.

Sketch *P*, Fig. 21, indicates how to get the best results

when welding round and up to a corner. The corner as indicated shows a pause has been made by the formation

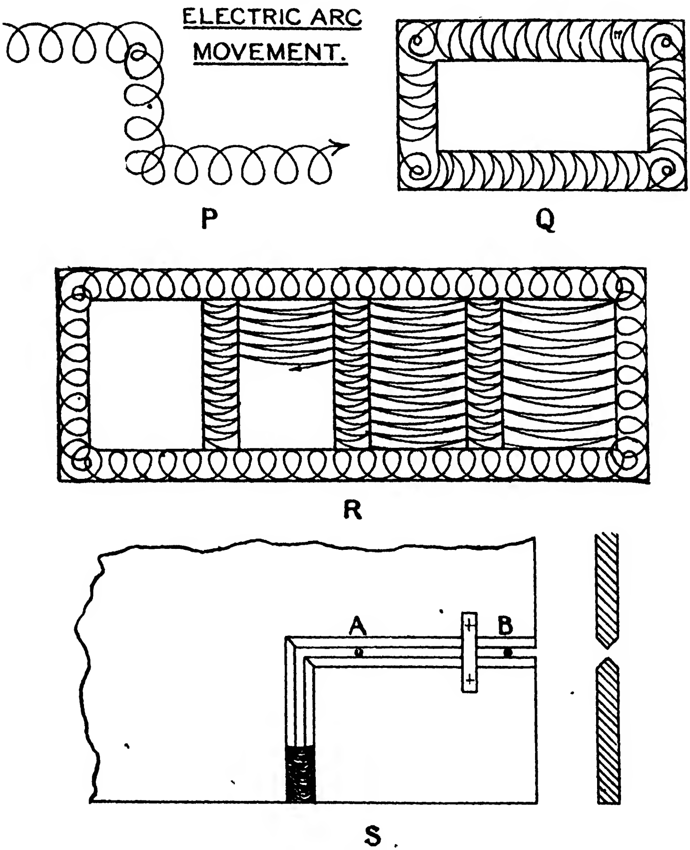


Fig. 21

of a double circle instead of the half-circle. This builds the corner, giving the desired quantity of metal, and helps to give a finished appearance to same. A good weld is

not always the most beautiful ; but it should be the operator's aim to please the eye with his work as well as carrying it out quickly.

Sketch *Q*, Fig. 21, shows a similar method of building the corners, and when welding a surface of an article. It is a good plan to outline the surface first to the required height, this afterwards being used as a guide to the subsequent work. This also prevents the arc from impinging upon the edges, which would be the case if the corners were left until the final operation.

Sketch *R*, Fig. 21, shows the outline of a method with inside guide layers, which is a good motion for surface building. Too much metal should not be put on at a time, but the width of the run be just sufficient to weld neatly, and to have perfect fusion. If on steel, the weld should be hammered at regular intervals, but should not be hammered when it has cooled down, as it will not only harden but hair cracks may be set up.

Sketch *S*, Fig. 21, shows a method of introducing a new piece of plate. A space is left as indicated all along the line for welding, and also the best position shown at which to commence. The joint is first prepared with the double Vee, then welding is done by operating on a portion at one side, then moving the flame over and doing the same on the opposite side. The metal should be hammered as the work proceeds, but only when at a bright red heat. *A* and *B* illustrate how wedges are driven in to set up opposite strains so as to obviate after-cracks.

Theory of Arc Welding. All kinds of theories have been put forward to account for the transference of metal across the electric arc, such as the force of gravity, electric propulsion, and so on, but the explanation which best fits into the facts of the phenomena is metallurgical rather than electrical.

Metals are not the simple elementary substances they are usually considered to be, but are compounds of a

complex character. The micro structure reveals something of this, but does not tell the whole story. Take the case of a mild steel electrode; the usual analysis gives iron, carbon, silicon, sulphur, phosphorus, and manganese; but in addition to these an ultimate analysis will often reveal nickel, copper, tin, arsenic, hydrogen, nitrogen, and oxygen; and may also at times show other elements.

When molten steel cools in the ingot mould, solidification does not take place in a perfectly homogeneous manner (this is further explained in the chapters on metals), but goes on in a selective way. In freezing, all the constituents do not keep in solution, consequently those of the higher melting point go into the solid state first of all and form microscopic dendritic or tree-like shapes, these being the nuclei of the crystal grains, which are composed of practically pure iron. The more impure portion, which is still liquid, due to its lower melting point, is pushed to the boundaries of the grains and there solidifies.

Now in the enormously rapid heating up of the end of the electrode, the metal of the grain boundaries is first melted and, expanding quickly, tends to push off a crystal of the metal, of which there are usually some millions to the cubic inch. This action probably accounts for the peculiar minute crackling sound which can be heard when a hard drawn wire is melted through the arc, the force of propulsion being greater due to the grains being in a state of great compression.

The above is probably one part of the action, the second being due to the rapid liberation of gases which carry over with them small globules of the metal. Then, thirdly, the sulphur in the steel is in the form of threads or globules of manganese sulphide, which melt at a very low temperature compared to that of iron. This compound is pretty certain to blow out of the steel and carry with it particles of iron. Indeed, careful examination of the deposited steel seems to bear this out, as while the sulphur content

is unaltered micro-examination shows it to be much more uniformly distributed in the weld metal than in the wire of the electrode.

For the coalescence of the metal particles it is fairly certain that surface tension plays an important part.

By very special methods photographic films have been taken which show the formation of the drops of molten metal on the tip of the electrode, and also their transference through the arc to the work being welded.

In downward welding, gravity will no doubt help to carry forward the molten metal of the outer part of the arc, as in overhead work this tends to fall away except where it is supported by the crater formed by the electrode lagging.

beneficial results from having a walk in the country, or a cycle run beside green fields, the green of the grass and the trees having a very soothing effect on the eyes, in addition to the breathing of the pure air after the vitiated atmosphere that usually obtains about welding work.

Copper as a Protecting Metal. Copper bar, plate and sheet can be considerably utilized in connection with welding, as it is easy to bend to the shape of joint on any broken portion to which it can be attached, and easily separated after the weld has been made. Thus, for instance, if a cast iron article is broken at some awkward part a piece of plate copper can be bent to the desired shape so as to support the broken portion. This portion can then be Vee'd and clamped to the copper. The arc can penetrate through the Vee and plate upon the copper without making an impression upon the latter. When the weld is completed the copper plate can be removed, leaving the surface of the cast iron article quite flush, and no dressing will be required.

Copper can also be used to protect holes from being filled up when a fracture passes through same and is being repaired. A bush can be made of about $\frac{1}{8}$ in. plate copper to the diameter of the hole. This can be firmly inserted, and after the welding has taken place be readily removed.

In the welding of thin pieces of iron or steel, sheet copper can be used to cover the underside of the joint which will prevent the metal from running through. Copper can also be used when holes are being filled up, as a piece of this metal can be fixed for the bottom of a hole and the metal deposited on same.

In filling in holes the end of the electrode should be continually pointed to the walls of the hole, at the same time the travel taking place round and round. If the metal begins to run too freely this, of course, is an indication of too much heat, and the current should be reduced.

It will not be out of place to emphasize again the necessity

for hammering welds that have been carried out in mild steel or wrought iron, and that this should be done whilst the metal is at a good heat.

Welding Cast Iron. One of the commonest complaints about electric welds which have been made on castings is that the material after welding is so difficult either to machine or to cut, and also that the edge of the weld is so extremely hard and brittle, that the least vibration in thin castings will cause a fracture alongside the weld. This is due to the high temperature to which the walls of the weld are raised, the graphite in the cast iron completely combining or going into solution with the iron and forming an extremely hard compound known as cementite or carbide of iron. The quick rate of cooling due to the heavy mass of metal conducting the heat from the small quantity of metal which is molten along the weld line, causes the latter to be "chilled," that is to say that there is not sufficient time for the graphite which is in solution to be thrown out again in cooling. There are two obvious remedies, one is to re-heat the weld and to allow for very slow cooling away from all draughts of cold air. The other remedy is to use such a flux on the electrode as will oppose the carbon going into solution. This latter method is one which possesses all the elements that make for the successful welding of cast iron, and from experiments which have been carried out there seems now to be no doubt that this will become the common way by which cast iron in the future will be welded to give a soft deposit.

In acetylene welding it is necessary to use a ferro-silicon rod, but with electric arc welding the conditions are entirely different, and a mild steel wire electrode with a suitbale flux ought to give the correct quality of deposit if the work is carried out properly.

The greatest care must be exercised in the welding of cast iron if the best result is to be obtained in the use of these specially coated electrodes. If it can be conveniently

done the work should be pre-heated to a temperature somewhat higher than the melting point of lead, and this can be quite easily tested by drawing a piece of sheet lead along the surface and observing if the remaining streak is melted. Care must be taken to adjust the current correctly so that the electrode metal will run freely but not too rapidly. When the arc is struck and proper contact made with the molten metal the point of the electrode must be moved in such a manner as to more or less puddle the molten metal, and this particularly so with regard to the edges of the weld. By this puddling the flux material will be worked into the molten metal, and as previously mentioned offer resistance to all the graphite going into solution.

After the weld is completed it must be protected in such a manner as to ensure slow cooling, both from the point of view of avoiding contraction fractures, and also to leave the deposited metal in a soft condition fit for machining.

There are many additional hints that might be given in connection with the welding of cast iron, but perhaps the following two or three will be sufficient.

In welding together two flat surfaces the tendency on cooling is for the joint to sink and the plate to settle in the form of a gutter. Therefore, to avoid this it is a good plan to pack up the joint a little out of the flat, so that when cooling has taken place the plate may be drawn back to the level. All kinds of methods are sometimes adopted, by bolting, clamping, etc., to restrain the contraction of the cast iron after cooling, but these, it need hardly be said, are of very little avail as the force of contraction in cast iron is so enormous and the metal usually so brittle that the casting will break either before or after being released. The careful avoidance of contraction strains is one of the things that the good welder is always thinking about on cast iron jobs, and this, in many cases, can be overcome by one or other method.

On some jobs it is a good plan, if no machining is required afterwards, to set up an opposing stress in the metal by the application of mechanical force, either by wedging or some other way, but this can only be applied to a limited number of jobs. A simple example of this class of operation is illustrated by the welding of the square frame or box shown in Fig. 24. Instead of pre-heating *C* which would have a tendency to press the metal over at *B*, a thin wedge *B* is driven gently into the prepared broken joint which will tend to put the metal away from the joint in a condition of compression, but after the weld has been made and contraction takes place this latter will be balanced by the compressive forces set up, and thus neutralize any possible strains.

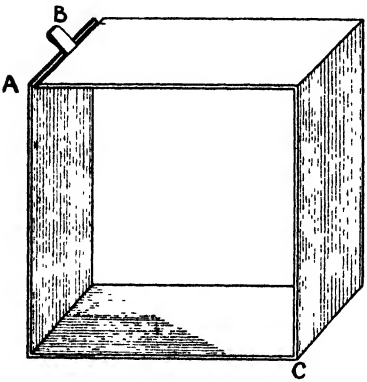


Fig. 24.—Cast Iron Box Broken at *A*

Wherever possible it is always advisable to reinforce the metal when repairing a cast iron fracture, the reinforcing being done by building up as much as convenient at that part of the joint where there would be no objection to the extra metal put on to give additional strength. The extra reinforcement, of course, takes the part of a pad on the top of the deposited metal in the Vee, and it is not a bad plan to make this pad about half as wide again as the top of the Vee.

Motor cylinders should always be pre-heated if they are to be electrically welded as very serious contraction strains will be set up in the metal when cooling, if the cylinder is not carefully heated before welding commences.

The inexperienced may easily be led astray by the ease with which a crack in the cylinder appears to be repaired without pre-heating, but he will be quickly disillusioned when he finds an ugly crack appear when the cylinder

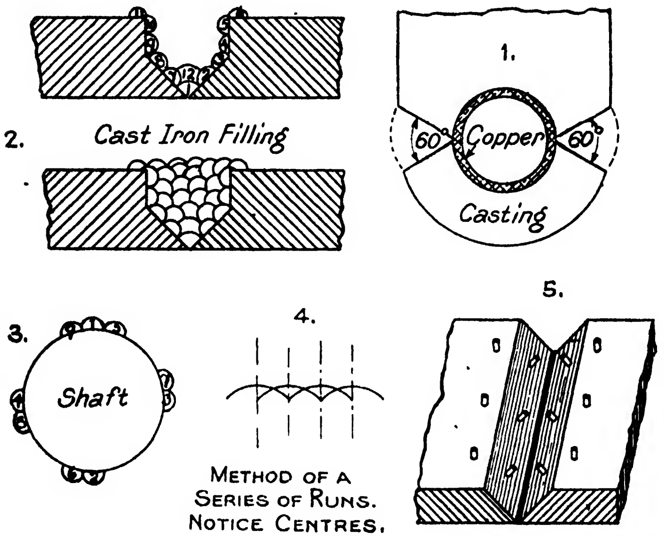


FIG. 25

(1) Method of protecting hole with copper.
(2) Method and order of runs on joint of cast iron.
(3) Method and order on building up shaft.
(4) Method of depositing metal for an overlay pad.
(5) Method of pegging cast iron.

has cooled down. Sometimes the fracture may be so fine in the weld that it is hardly perceptible.

To Detect Cracks in the Metal. Smear the surface of the metal with thin oil and allowing it to stand for a few minutes; then the oil should be carefully cleaned away with a piece of waste or rag, and the surface rubbed with chalk and smoothed down with the hand. If there is a fine crack in the metal the oil in same in the course of a

few minutes will gradually work out and show its presence in the chalk on the surface. Before re-welding all oil must be carefully cleaned away from the joint, as its presence is detrimental to the making of a good arc, and this will, of course, affect the quality of the weld.

It is of little use trying to weld cast iron that has been corroded by sea water or other means, and has had its carbon in the iron released as graphite which can be scraped away with a knife in the form of black-lead powder. If the operator attempts to weld metal of this description he will find that where the arc is struck a cavity will be made, or the metal will just bubble up. In some cases an apparently good weld will be made, but when this has cooled down it will be found that the deposited metal can be lifted up by the insertion of a chisel.

Pegging of Cast Iron. When jobs have to be welded in graphitic cast iron as mentioned above, it is best to peg the joint as shown in Fig. 25, No. 5, by drilling holes, tapping, and screwing in a series of mild steel pegs. The pegs will be merged and welded in to the deposited metal, give strength to the joint, and thus enable the operator to make the best of a bad job.

The above form of spongy cast iron can generally be tested by a hammer and chisel, and if it is found to break away in powder this will give an indication of the difficulties that a welder is up against in attempting to make a success of this kind of metal.

Finally, it can be taken as a general rule that without a foundation of good metal it is extremely difficult to make a presentable job, and often a waste of time and good material to attempt same.

CHAPTER VI

DON'TS FOR THE GUIDANCE OF ELECTRIC WELDERS

DON'T take any risks. " Safety first " is always the best policy. Be careful to watch against that familiarity which leads to carelessness.

Don't weld where there are other workers in the vicinity, unless a screen is provided for the protection of their eyes.

Don't weld without proper protection to—(*a*) your eyes, (*b*) your face and neck, (*c*) and protection for the body as well as your clothes. Always wear gauntlet gloves for hand and arm protection, and also use all other means that are provided for your welfare.

Don't look at the arc with uncovered eyes, remember the dangers of the light rays and keep behind the welding screen.

Don't wear a celluloid collar, as the sparks from the arc may set it on fire and cause serious results.

Don't weld beside a white-washed wall or any other surface that will reflect light, as the injurious rays can be reflected and in this way may cause eye trouble or skin burn. If you are obliged to weld beside any surface that reflects take care to provide yourself with sides on your screen, and arrange pieces of cardboard to fit on your plain goggles.

Don't be without " first aid " appliances, and see these contain some suitable oil for the dressing of burns.

Don't plunge your foot into a bucket of water if a globule of metal enters your boot, as it may cause a scald in addition to a burn, but remove the boot quickly. Always remember that a better plan is to adopt a method of prevention so that the foot can be protected from the dropping metal.

Don't hammer a weld without using the plain goggles to protect the eyes from flying particles of scale. For good results on a weld hammering is essential.

Don't take out your portable electric plant unless your equipment includes a fire extinguisher.

Don't experiment with an actual job, as it is rather a dangerous practice. Always do your experimenting on pieces that can be tested to destruction, and which are not part of an actual job.

Don't weld whilst standing on a wet or damp floor, it is not particularly dangerous but unpleasant to receive a slight shock which may be caused through the current passing to earth through the body. It is always better to stand upon a piece of dry wood.

Don't forget to keep a collection of pieces of carbon and copper tubing, and sheet, as these will come in very useful to support and protect holes when carrying out welds in these positions.

Don't break the arc slowly when finishing an electrode or line of welding. Increasing the gap or length of arc generally means burning the metal and leaving cavities in same. When breaking the arc do it as quickly as possible.

Don't get slovenly in your preparation of work, as this may mean a serious accident if the job is faulty. Always study the work first and arrange to overcome any difficulties that are likely to crop up. Remember your reputation depends upon good welding.

Don't grip your electrode holder too tightly, as tension of the sinews tends to unsteadiness of the arc. Just grip the holder firmly without undue strain.

Don't allow too much cable to dangle from the holder, as this also tends to make an unsteady arc, due to the swing of the cable. Always support the cable over your knee when seated, and when standing support the cable with the hand that holds the screen, just allowing sufficient for free movement without any undue length to dangle.

Don't weld in a standing position, as work can often be carried out much more efficiently when comfortably seated, and a more accurate adjustment of the arc maintained.

Don't take any risks as to the polarity of the connection, always make sure which is the positive end and see that the wires are attached correctly.

Don't have any slack joints, as these will create a series of small arcs which may give off sparks causing a fire if anything of an inflammable nature is near them. Always make the joints secure by bolts and nuts, and tighten these with a spanner.

Don't run the machine when you are not welding. If you are about to do other work that will take some time shut down the machine. Always bear in mind the expense of running a plant and that unnecessary running means extra expense which has got to be borne by someone.

Don't be mistaken between running flux or slag and molten metal when using heavily coated electrodes. The flux is usually of a light red colour, the tint of the metal being somewhat darker, a little practice will soon enable you to tell the difference.

Don't allow the flux to flow in front of the metal. Its main duty is to protect the metal from coming into contact with the oxygen of the atmosphere. For this purpose, therefore, the flux should always be on top of the molten metal.

Don't have too large an arc when welding, as this will not only cause a waste of metal but will tend to oxidize the metal that it is depositing, and also to form the objectionable nitrite of iron which is found in some welded joints. Always keep the arc as short as possible, just sufficient to allow the metal to flow freely.

Don't attempt to weld any metal without a chemical re-agent or flux. Whilst some people advocate the use of bare wire electrodes, general experience shows that the best results can be obtained when electrodes are coated, even if it only be with a wash coat.

Don't attempt to deposit too much metal at one spot or at one time, as too large a mass of molten metal at one

spot tends to cause blow-holes, and may also, through too high a local heat, cause a rupture. It is a good plan to deposit a little at a time and see that the slag is not bottled up in the weld.

Don't forget when building up worn journals on a shaft to run the metal around the shaft first one side then on the other so as to minimize distortion of the shaft.

Don't weld a small article unless it is secured to the table with clamps, as the work may be lifted by the electrode, thus causing hard spots by the continual make and break, possibly spoiling the surface which is being welded.

Don't forget if the electrode does make a short or stick to the work to quickly move it from right to left, and thus break it away.

Don't tamper or experiment with chemicals for fluxes unless you understand something of their functions. It needs the knowledge of a chemist to thoroughly compound or mix the ingredients. In addition fluxes properly made up can be readily procured from people who understand their use, and the welder will find this best in the end.

Don't mix the fluxes too thin if you coat your own electrodes, or generally they will not do what the manufacturers intend them to do. As a rule, fluxes should be mixed to a paste of the consistency of treacle, and the coating well applied to the electrodes which should afterwards be allowed to dry.

Don't forget to adjust the current strength to suit not only the type of electrode being used but also the kind of wrapping or flux coating it has. It is a good plan to err on the low side with the current until experience is gained.

Don't forget that electrodes, fluxes, and electric current cost money, hence, avoid all waste, and think out the most economical methods of working.

Don't commence welding until everything is ready, as it is essential that a partly finished weld should not be left

whilst the welder finds further tackle. Therefore, get everything ready first; even if it takes a little longer to make a start it will be quicker in the end.

Don't get disheartened if during your experimental and trial stages you get some failures, keep plodding along watching all the points, and success will ultimately come.

Don't at the commencement dabble in the welding of all kinds of metals, master them one at a time.

Don't use cheap or common welding wires, procure the best even if it costs a little higher, obtaining your supplies from manufacturers who specialize in welding wires and know what is required for the best results. (*See* advertisement at beginning of book.)

Don't weld along a job too quickly, unless on thin material or the filling up of a hole. In the latter case it is advisable to alter the angle and the position of the electrode, moving along quickly and at the same time making small gyrations or circles.

Don't attempt to weld on an oily surface, as it sets up resistance to the formation of the arc, and at the same time repels the deposition of the metal.

Don't, when using fluxes, leave the lids off the tins which contain same, as when in contact with the atmosphere they often depreciate in value.

Don't forget to see that the terminals on the switchboard or portable van are definitely marked, as this saves a lot of time and enables others to use the same set without testing the terminals.

Don't attempt to weld castings that have been graphitisized by contact with sea or other water, or castings that have been oxidized by being placed in and out of a furnace, or have come in contact with furnace gases for a long period.

Don't keep coated electrodes in a damp place. If you carry a stock of these they should be stored in a dry room.

Don't forget to occasionally overhaul the tackle, such as

clamps, bolts, etc., to see that it is in such condition that it can be readily used when required. All these things should be attended to during the slack time between jobs.

Don't forget that wood screens are essential for working in boilers and tanks. The use of sheet iron is objectionable, as it is pretty certain to give trouble in making contact.

Don't forget that a beginner should start practising on plate of heavy section, say, about $\frac{3}{8}$ in. or $\frac{1}{2}$ in. thick, and this should take the form of a series of runs of about $\frac{1}{4}$ in. wide in the surface of the plate, aiming to keep the deposit in a straight line, which will be found somewhat difficult until he has had a fair amount of practice. In acquiring the art of steadying the electrode the welder should also endeavour to acquire the proper sense of touch, as upon this depends the deposition of good metal. The beginner is usually inclined to make too long an arc, but this should be reduced until he can keep the distance to a maximum of $\frac{3}{16}$ in. for general work. The welder should be again reminded that variation in the length of the arc will cause considerable variation in the quality of the metal which is laid down.

Don't be content with just being able to deposit the metal, but carefully test same by means of a hammer and chisel, to see that it is of tough quality and free from blow-holes. After a welder has made satisfactory progress on single runs then double runs can be attempted, care being taken that all slag from the first run is removed before the second layer is deposited. After some practice with horizontal deposition the next step for the welder is to attempt depositing in a vertical position, and then overhead. Along with all this practice test pieces should be made and the quality of the weld determined by bending in the vice and also actual breaking in the testing machine.

Don't forget that although electric welding in many cases minimizes the necessity of pre-heating through small local dispersion of heat, there is still need to watch for the evidence

of expansion and contraction, or serious failures will result. The chapter dealing with that subject should be consulted for general advice. But in any case, wherever possible, it is always an advantage not only to pre-heat the work but to allow it to cool slowly, as it is never advisable in important work to take any risks.

Finally—

Don't forget to read all you can about the subject, and to explore every channel for information, as so much depends upon the individual welder, and there is certainly plenty of scope for the good, thoughtful welder who really knows his job.

CHAPTER VII

GAS WELDING

Explosions : Their Cause and Avoidance. Whilst with ordinary care there is very little danger of explosion in the use of acetylene, it is well to know in which directions dangers lie, so that these may be avoided. In the early days of the use of acetylene, explosions were fairly common, but since a careful study has been made of all the properties of acetylene, and the various conditions that may be set up in its use, dangers from explosion have become very rare.

It may be taken that every kind of explosion is due to some form of increased pressure, either in connection with the acetylene itself, the gases which form its products of combustion, or in connection with the storage or mis-use of the oxygen which is used in the carrying out of acetylene welding.

Increase of pressure may be caused in two ways—

(1) Increase of pressure without the firing of gas or gases.

(2) Increase of pressure caused through the firing of gases.

A good illustration of the first cause is in the case of a closed vessel which contains water and carbide of calcium, as acetylene will be continually generated so long as there is any carbide present in contact with the water, the internal pressure continually increasing until the vessel bursts. Care should, therefore, be taken to avoid damp carbide being removed from a generator and placed back in a close storage cylinder as is sometimes done, resulting in the lid being blown from the head of the drum.

What has been mentioned above with regard to the increase of pressure due to the generation of carbide in a closed drum will, of course, apply to any kind of an acetylene gas holder where no safety valve provision is

made for the gas to blow out when it has attained a definite pressure.

A similiar illustration of the increase of pressure without firing may be given in the re-filling of small oxygen cylinders from larger ones. It seems almost incredible, but a case of this kind happened recently in which an operator filled a small cylinder from a larger one by using a connecting pipe between the two, placing the small cylinder under his arm and judging as to the right quantity which it should contain by feeling the sides of the steel cylinder swell out like the bladder of a bagpipe. After one or two fillings of this description the cylinder burst with fatal results. Cylinders should never be filled from one to another without the greatest possible care, and only under exceptional circumstances. It will be readily seen that a cylinder which is designed to carry a pressure of only 400 lbs. can easily be burst by connecting it up to a larger cylinder which has a pressure of 1,800 lbs. to the square inch. If the small cylinder is very small as compared with the larger one the pressure of equilibrium when the two cylinders are connected may only drop to 1,600 lbs. to the square inch, this in many cases being sufficient to burst a small cylinder.

The pressure of gas in vessels is directly proportional to the quantity of gas forced into the vessel, thus, if a cylinder is open to the atmosphere the pressure of the gas inside will be the same as that of the air, say 15 lbs. to the square inch. Now if twice the quantity or weight of gas is put in the cylinder the pressure will be increased to 30 lbs. the square inch. So if ten times the amount of gas is forced into a vessel the resultant pressure will be ten times 15, that is 150 lbs. to the square inch. From this it will be readily seen that the internal pressure of a cylinder rapidly increases with increase in the quantity of gas forced into the cylinder.

The increase of pressure due to the firing of mixed gases

is usually very much greater than that which is obtained by increase of pressure without firing, and in the case of explosions attended with correspondingly more serious results. In this case the increase of pressure may be due to the evolution of an additional quantity of gas and also to a rapid rise in the temperature of the gases. Apart from any increase in the quantity of gas evolved in an explosion, pressure of gases is doubled if the rise of temperature amounts to 273° C., and as in an explosion the rise of temperature may be as much as four or five times this amount, the corresponding increase of pressure will be proportionally great.

When two gases are mixed, one being what may be called a fuel gas, and the other a supporter of combustion, like oxygen, if sufficient heat by any means is conveyed to the gas to cause ignition, then an explosion will inevitably ensue if the proportion of gas comes within range of an explosive mixture.

It is as well to remember that acetylene, of all gases, has possibly the greatest explosive range, for firing will take place when air is mixed with even 3 per cent of acetylene right up to when the mixture contains about 80 per cent of the same gas. It is, therefore, evident from what has been said that the greatest possible care should be exercised so that leakage of acetylene should not take place especially in confined places. Explosions occasionally take place even in a large open workshop where the gas has been allowed to leak and a certain volume of air has become impregnated with the same. If a piece of red hot iron or a lighted blow-pipe comes near this an explosion will ensue which will set up a quick movement of the air which may cause serious damage in addition to any results from fire which may follow.

If an explosive mixture is contained in a cylinder the only way to stop the flame back-firing into it and exploding same, is that the orifice in the passage to the cylinder shall

be very small. In the case of acetylene this should not be larger than $\frac{1}{30}$ in.

As every mixture of gases has a certain velocity of flame propagation, that is, the flame will back-fire along a tube to the vessel containing the gas at a certain definite velocity, but if the gases are coming out at a greater speed than this backward flame velocity then there is no danger of back-firing. This indeed gives the explanation of back-firing in some forms of defective blow-pipes.

Instances are on record of most serious explosions having taken place through two gases, such as hydrogen and oxygen, having become mixed in the same cylinder and being exploded by back-firing.

In spite of all precautions that are taken, gases do very occasionally get mixed in a cylinder, so that it is a wise precaution to take in cases where it is found difficult to couple the regulator to a cylinder, or if, in the last resort, the flame of the blow-pipe should show anything uncommon, to immediately disconnect the cylinder and return it with a request for examination to the filling depot.

Acetylene differs from elementary gases such as oxygen and hydrogen in being a compound gas which is capable of what is known as polymerization, which means to say that under certain conditions of either pressure or heat, or both of these combined, the gas may split up into other compounds with great increase of pressure. It should, therefore, never be used in its free state at a greater pressure than about nine pounds to the square inch. When the pressure is increased more than this the acetylene may explode under the provocation of a sharp blow or knock upon the metallic containing vessel.

To avoid explosions care should also be taken in the proper disposal of the spent carbide from generators. Cases have occurred where spent carbide has been washed down drains and gone into sewers, carrying with it some of the slightly unspent carbide which has generated the

acetylene in the sewer mains, and this becoming ignited by a stray light causing a most serious explosion, the effect of which was carried a considerable distance along sewer pipes, drains, etc. In any case, however the spent carbide from generators is disposed of, it should first be entirely killed by being well flooded with water, and this should be done in an open space.

Empty carbide drums should always be filled with water to push out the residual acetylene, before they are thrown out into a yard or open space. Serious explosions have occurred through children bringing lights near.

There is one other source of danger which can hardly be called an explosion, but which, nevertheless, has serious effects, and that is in the improper use of gauges. In a freshly filled oxygen cylinder it is sometimes forgotten that the pressure per square inch is very large, running out to about 1,800 lbs. Now, if the valve of this cylinder is opened suddenly, the sudden rush of gas into the tube of the pressure gauge is sometimes sufficient to fracture same, especially if the gauge has been in use some time. The full pressure of the gas being let loose into the body of the gauge will be quite sufficient to burst the dial glass and may cause serious facial or other injury to the individual who is operating the valve key.

In general use there is really very little need to have a pressure gauge on a cylinder at all, as all that is required is to have an efficient regulator to reduce the gases to the required pressure for the blow-pipe. The use of a pressure gauge should be confined to testing the quantity of gas in a cylinder, if this is required, which, in practice, is not very often.

CHAPTER VIII

OXY-ACETYLENE WELDING EQUIPMENT

No welding job of any importance can be considered complete which only operates with the electric arc process, for whilst this latter has a large sphere of usefulness it is certain that some jobs can be better done with the use of the oxy-acetylene blow-pipe. There is not the slightest need for any prejudice to exist in favour of either one or other of the processes as each has its own field of operation which can be quite easily found out where the two processes are run side by side. A good welder, therefore, should endeavour to get a working knowledge of each process so that if he should happen to be the sole operator in a works he will be able to manipulate either as required.

Systems of Welding. Three systems of welding are in operation, namely, High Pressure, Medium Pressure, and Low Pressure. The two which are most popular in England are the High Pressure and the Low Pressure systems.

High Pressure System

The use of a portable equipment for the welding and cutting of metals in connection with either constructional, destructional, or repair work offers very great advantages, and many years' experience of the high pressure system proves it to be by far the best kind of portable plant that can be arranged. Whilst it is true that the cost of compressed acetylene as used by this method is much greater than that obtained from a generator, its great convenience altogether outbalances the extra cost. The dissolved acetylene, or D.A. as it is called, is supplied in cylinders generally containing 200 cu. ft. from which a supply of 80 or 90 cu. ft. of pure, cool, and dry acetylene can be

obtained per hour. Smaller cylinders of 100 cu. ft. or 60 cu. ft. are also supplied according to requirements, but, as a general rule, the larger cylinders are used. The advantages of this system may be summarized as follows—

(1) Simplicity of handling, which makes it possible for the operator to manipulate his own plant and bring it close up to the work.

(2) The acetylene being in cylinders ensures portability and these can be arranged so as to form a battery which, together with the necessary oxygen cylinders, will form an installation when much work is to be undertaken.

(3) The component parts are easy to assemble or dissemble, thus avoiding all risks of damage in transit.

(4) The elimination of labour charges for attendance to plant on account of there being neither water, carbide, purifying material, or residue to handle.

(5) The gas in the cylinder is under perfect control, and needs no attention whilst either in or out of use.

(6) The supply of acetylene from the cylinder to the blow-pipe is automatically controlled by a regulating valve which maintains a constant pressure of the gas in the same manner as with the oxygen. This enables the operator to adjust the pressure to suit the size of blow-pipe and the job to be worked on.

(7) The temperature of the acetylene is never above the normal, no matter what the rate of consumption.

(8) The acetylene from the cylinder is always of the highest degree of purity, which enables the operator to make the best quality of weld, as explained in Chapter XVI.

(9) No licence is needed for the storing of D.A. cylinders.

High Pressure Equipment. A complete plant for the high pressure system will be made up as follows—

(1) High pressure blow-pipe with separate oxygen control and various sized tips for different thicknesses.

(2) Cylinders of acetylene as required.

(3) Acetylene pressure gauge with regulator valve.

(4) Two 10 ft. lengths of $\frac{3}{8}$ in. high pressure rubber tube with clips.

(5) Oxygen cylinders as required.

(6) Oxygen pressure gauge.

(7) Oxygen regulator valve.

(8) One pair of welding goggles.

(9) Keys to fit cylinders and spanners for gland nuts, also for fixing the regulators to the cylinders.

The above comprises a complete outfit of the high pressure system for welding, but if cutting is required to be done the following additions will be necessary—

(10) Oxy-acetylene cutting blow-pipe with spare nozzles.

(11) Special regulator valve for oxygen cylinders, which gives a wider range of adjustment than the ordinary valve and is essential when cutting thick sections.

(12) One pair of spare goggles.

Acetylene and Oxygen Cylinders. The following table gives some particulars relating to these—

	Contents in cu. ft. when fully charged.	External dia. in inches.	Length over all in inches.	Weight in lbs. when empty.
Acetylene Cylinders .	60 100 200	$6\frac{1}{4}$ $8\frac{1}{4}$ $10\frac{1}{2}$	$41\frac{1}{2}$ 40 $52\frac{1}{2}$	64 95 195
Oxygen Cylinders .	80 100	7 7	41 49	85 103

Patent D.A. Blow-pipe. This blow-pipe has twelve interchangeable tips, graded for welding metals from about 21 gauge ($\frac{1}{32}$ in. thickness) upwards. It is specially designed for use with the high pressure system. Some of the advantages of this blow-pipe are as follows.

The mixing chamber of the blow-pipe contains porous material which effectively prevents back-firing dangers.

The blow-pipe is fitted with a thumb screw on the oxygen inlet, thus enabling the operator to regulate or cut off the oxygen supply quickly. In cases where work is being executed in a confined space this is of great value, as the operator does not need to leave the work in order to go to the gas cylinder to adjust the regulator.

From the point of view of economy the D.A. blow-pipes are extremely efficient in as much as they consume the minimum amount of gases, the tips being carefully made so that the actual consumption of gas can be readily gauged for the purpose of calculating cost.

APPROXIMATE CONSUMPTION OF GASES AND WORKING PRESSURES REQUIRED FOR THE VARIOUS TIPS. D.A. BLOW-PIPES

	Blowpipe Tip No.	50	75	100	150	225	350	500	1000
Acetylene	Cubic ft. per hr.	1·75	2·66	3·5	5·25	7·75	12·25	17·25	36
	Press. in lbs. ,,	2	2	2	2	2·5	3	4	7·5
Oxygen	Cubic ft per hr.	2 33	3·25	4·25	7	17·375	16·125	24	46
	Press. in lbs. ,,	4	4	4	4	4 5	5	7 5	15
Approx. thickness for most economical results .		1/32	1/24	1/16	1/12	1/8	3/16	5/16	1"

Larger tips are also supplied, numbered 1,500, 2,000, 2,500, for very heavy work, but of course it will be understood that the quality and quantity of work obtained by the use of any particular tip will vary considerably according to the skill of the operator.

D.A. Cylinders. Cylinders for dissolved acetylene are manufactured from the best quality steel plate or tube, the ends usually being attached by welding. To avoid bad construction and resulting accident certain Government regulations are laid down which govern the process of manufacture.

The cylinders are completely filled with a porous material such as kapok fibre or other substance, this afterwards being completely saturated with acetone, a liquid somewhat similar to alcohol, and which has the remarkable property of dissolving a large volume of acetylene gas. It is absolutely essential that there should be no pockets of gas or unfilled spaces in the cylinder, in order to obviate

any danger of explosion due to shock or impact on the cylinder.

The gas used for charging the cylinders, after being generated, is carefully purified, as any impurities in the acetylene makes it extremely difficult for the gas to go into solution with the acetone. This latter is an advantage from the point of view of the user, as it ensures him getting a supply of pure gas.

Medium Pressure System

In this system the acetylene, after generation, is usually stored in a gasometer at pressures varying from 40 ins. to 80 ins. of water, that is at about 1½ lbs. to 3 lbs. per square inch. Whilst the high pressure blow-pipe is not suitable for medium pressure acetylene, the construction of a suitable blow-pipe varies very little from it. The oxygen in this blow-pipe is used at a slightly higher pressure than the acetylene which necessitates a somewhat different construction of blow-pipe. Special blow-pipes for medium pressure work can, of course, be readily obtained. As the pressure of the oxygen used for this class of blow-pipe is higher than the acetylene a safety device must be used to prevent the passage of the oxygen to the gasometer.

Low Pressure System

Generators. For this system a generator is required, the acetylene being generated and stored in the holder at a pressure of from 3 ins. to 10 ins. of water, say an average of 5 ins., which is equivalent to just about ¼ lb. to the square inch.

There are many kinds and makes of generators on the market, but they can all be classed under the two headings —" Water to Carbide " or " Carbide to Water," being either automatic or non-automatic in the control of the gas generator. The diagrammatic sketches Nos. 1 to 4, Fig. 26, illustrate the working of the different types of generators. It is advisable that the generator should

always be on the large side so as to generate a volume of gas which is somewhat in excess of requirements. Many firms make a mistake in procuring a small generator, and

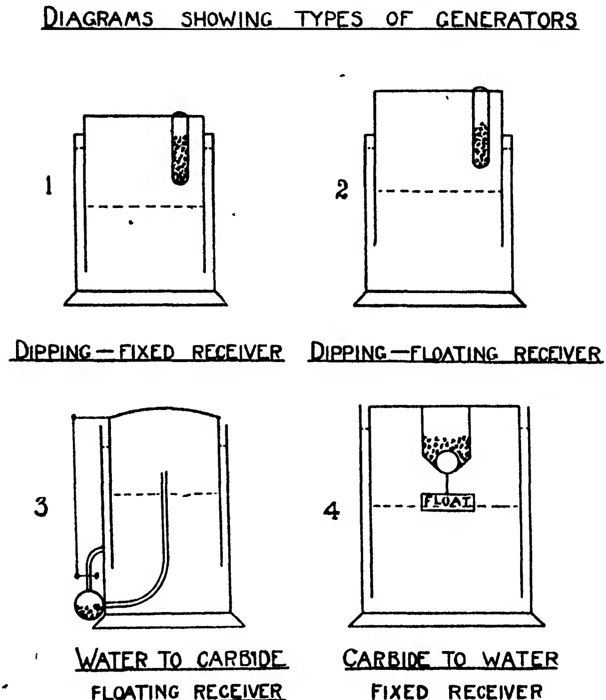


FIG 26

find out as work increases that they are unable to obtain the necessary supply of gas to deal with heavy work. It is the best and the most profitable plan to obtain a generator of good capacity at the outset, so as to meet additional requirements as the need increases. A restricted supply of gas to the blow-pipe is fatal to the carrying out of good work.

Generators having two charging chambers usually give very good results as a continuous supply of gas can be maintained. While one chamber is generating, the other can be charged with carbide and the generation of gas kept going continuously so long as the work makes the demand. Generators with single charging chambers, especially if generators be on the small side, cause a waste of valuable time. There also exists a tendency to generate too quickly, which will result in impure gas and consequent faulty welding.

Care should be taken to see that all air is removed from the gas container before it is filled with acetylene, as an explosive mixture may be set up if this precaution is neglected.

The generator should be in an outhouse and so arranged that air can circulate about it by having a free flow of air right through the building.

The generator should have low pressure in all parts, including the connecting pipes. The generator should be so designed as to give the greatest volume of acetylene that it is possible to obtain from a given quantity of carbide.

As the purity of the gas depends upon the temperature of generation, and this latter upon the speed, the generator should not be forced, but the gas allowed to pass into the holder at the lowest possible temperature.

The residue or lime sludge when removed from the charging chambers should be put into a container with about ten times its weight of water, so that any unspent carbide may be completely neutralized and the resulting acetylene driven off in the open air. Unspent carbide being washed down drains or into sewers may cause a serious explosion to take place.

Every welding equipment must have a drum of ample capacity for the storage of carbide, which can be hermetically sealed. It should be fixed 4 or 5 ins. above the ground in such a position as to have air freely passing

about it. The lid should never be allowed to remain off the drum, but immediately replaced when the carbide has been taken out. It is as well to remember that the humidity in the atmosphere is sufficient to set up slow generation of acetylene which would cause disastrous results if a light or spark came anywhere near an unsecured drum. Unused carbide removed from a charging chamber should never be replaced in a drum, as this nearly always contains some moisture which will cause generation to continue which may burst the drum.

Purifier. As generated acetylene always contains impurities, such as phosphorated hydrogen and sulphurated hydrogen, which affect the quality of the weld, it is essential that the gases be passed through some form of purifying material before going on to the blow-pipe. The impurities mentioned above cannot be removed by mechanical means, such as passing the gas through coke, sawdust, etc., but must be passed through some material that will mechanically re-act and trap the impurities. Several purifying materials, which are more or less useful, are on the market at the present time. The other impurities contained in acetylene are ammonia and lime dust; these can be removed if the acetylene is allowed to pass up through water in very small bubbles, and it is usually done by the gas, after being generated, passing up through the water of the generator tank.

Hydraulic Safety Valve. On account of the pressure of the oxygen always being greater than that of the acetylene, in the low pressure system, it is absolutely essential that some method should be adopted to stop the oxygen from forcing its way along the connecting tubes and thus getting mixed with the acetylene in the holder of the generator; or in the case of a back-fire, the necessary oxygen should be supplied to enable the flame to pass right along the connecting tubes to the generator.

The device commonly in use to overcome this source of

danger is now the well-known hydraulic safety valve as shown and explained in Figs. 27 and 28. This safety valve is the most essential and necessary part of a welding installation, and must always receive regular daily attention if danger is to be avoided.

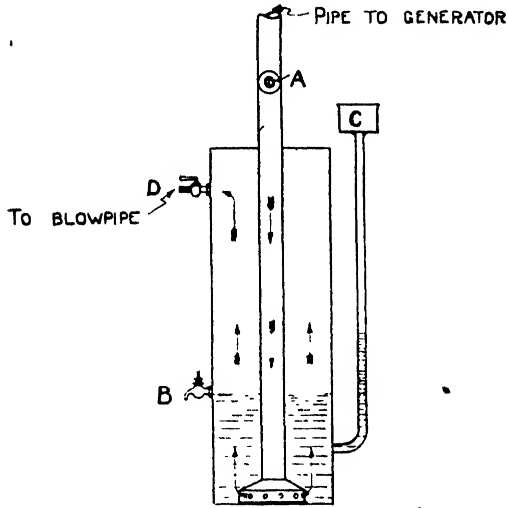


FIG. 27.—ACETYLENE GAS PASSING THROUGH HYDRAULIC BACK PRESSURE VALVE

If through any defect in the blow-pipe, stoppage at the tip of the nozzle, ill regulation of the flame, or for any other cause a back-fire is set up, this will be immediately arrested at the hydraulic safety valve by diverting the exploded mixture into the atmosphere, the water in the safety valve effectually plugging up the tube which leads back to the generator and so keeping the oxygen from passing along into same.

Tubing. This should always be of the best type for use with acetylene and oxygen, preferably of the three-ply

character and covered with asbestos; it will then offer the greatest resistance to ill usage and to being burnt with sparks from the blow-pipe.

Blow-pipe. There are many makes and styles of blow-pipes suitable for the low pressure system. It hardly need be said that the best blow-pipe is the cheapest in

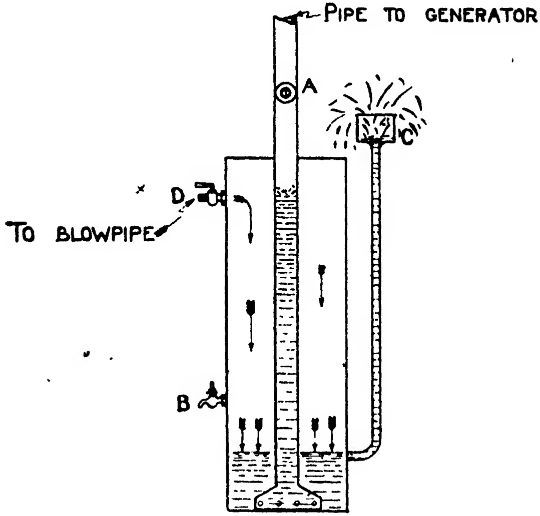


FIG 28.—HYDRAULIC BACK PRESSURE VALVE IN ACTION WHEN BACK FIRE TAKES PLACE

the long run. For general use the universal type is very convenient, this being provided in two sizes with different sized nozzles, according to the thickness of the work to be welded. Unless the blow-pipes are to be used on work of a special character it is advisable to have nozzles which can be used to execute work of a very light and also of a heavy description

Regulator, Goggles, etc. The regulator is required for reducing the pressure of the oxygen from, say, 1,800 lbs.

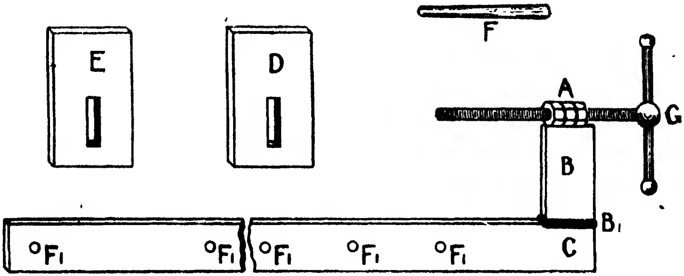


FIG 29.—CLAMP FOR CRANK CASES OR LARGE WORK
VERY USEFUL TOOL FOR WELDERS

A = 3 ¾" nuts welded to B.
B is 4 × ½" Welded B_1 to piece of same section at any length.
C has a series of ½" holes drilled to take steel cottar F.
E and D fit over C one at each side of the work which has to be straightened.
F = 2 steel pins ½ dia. to fit in holes.
The work then is secured by screw G.

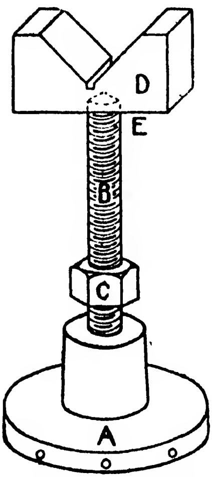


FIG. 30.—AN ADJUSTABLE DIE BLOCK FOR SUPPORTING SHAFTS OF UNEVEN DIAMS. IN ONE LENGTH

A = Cast iron flange tapped ¾".
B = ¾" Studding.
C = ¾" Nut.
D = Cast iron V block.

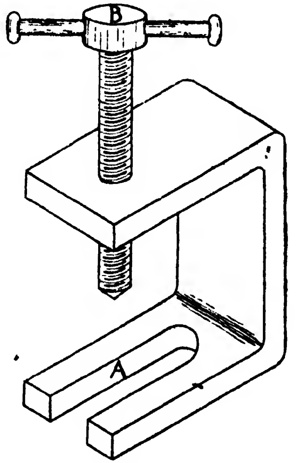


FIG. 31.—HOLDER FOR ADJUSTABLE DIE BLOCK

A fits over the adjustable block at E and the work in the vee is secured by the screw B of holder. Small jobs can be secured by this holder so that when making a short arc it will not lift up the work.

per square inch, the full cylinder pressure, to any pressure required for welding or cutting. Oxygen regulators are fitted with a right-hand thread as distinct from the acetylene regulator with the left-hand thread.

A cylinder key for opening and closing the cylinder valve is also required, and a spanner to tighten up the gland nut.

Suitable goggles are, of course, also required.

Pre-heating Stove, etc. There are many kinds of gas heated stoves, and a good one should be procured which is accessible both from the top and the sides. It is advisable to have the sides fitted with hinged doors so that whichever portion of the work needs welding the corresponding door can be opened and the job repaired in position.

A smith's hearth is also essential for the welding shop, as this will come in handy for many purposes. It is useful to have a supply of fire-bricks so that a fire may be arranged of any size or shape to suit the requirements of the work.

Plaster of Paris occasionally comes in handy for the making of a simple pattern for a missing portion, or it can be used for making a mould from which a missing portion can be cast if only of small dimensions.

A table with a machine face for setting up work is also required, and it will be an advantage to have an additional one with a slab top. Further to the above it will be necessary to have tongs, grabs, clamps (Figs. 14 and 29). plates and bolts, leather apron, gauntlets, and a cupboard for the storage of fluxes, rods, etc. An adjustable Vee block and holder for same are illustrated in Figs. 30 and 31.

CHAPTER IX

PREPARATION OF JOINTS FOR OXY-ACETYLENE WELDING

Preparation of Joints, etc. If welding operations are to be carried out successfully it is essential that the joints should be thoroughly prepared. In general repairing nearly every job must be considered by itself, and the welder should try to imagine what is likely to happen during the process of welding and the subsequent cooling. Once he has developed his imagination on these lines half of the difficulties will disappear, and he can prepare and set up his work according to what he anticipates will take place. It cannot be too often reiterated that "thinking must be done before the job is commenced, and not after it is welded and possibly spoilt."

Cleanliness of the metal surface is as essential as the Veeing of the material, not only in the Vee but on each side of same. Mechanical cleaning will very much assist the chemical cleaning which takes place either through the reducing gases of the blow-pipe or the flux which is used.

The welding of thin metals presents a good deal of difficulty to a beginner. However, he should persevere with this kind of material until the art of jointing thin sheets has been completely mastered.

In the preparing of a joint care should be taken when bevelling to see that each side is ground or cut away equally, thus ensuring the same thickness on each side of the Vee as this will greatly assist in the operation of welding, the welding being uniform and the flow of metal even.

Thin pieces need not be Vee'd, but the joint and the jointing surface should be thoroughly clean. A good plan for thin plate joints is to raise the edges about $\frac{1}{8}$ in., and this, with care, will act as the filling material. When the

weld is complete the joint can then be hammered flat on the anvil.

Joints up to $\frac{1}{4}$ in. ought to have a single Vee, above $\frac{1}{4}$ in. it is better to have a double Vee, otherwise the channel would be very wide. A good angle for the Vee to ensure correct penetration is 90°, this being somewhat wider than that required for electric welding, namely, 60°. A practical and simple method of testing the angle for 90° is to place the two bevel plates together to see if they form a complete angle bend like the two sides of a picture frame. Another plan is to lay the two plates edge to edge; and to try a small square in the Vee to test it for the 90° as required.

Before any mechanical preparation is commenced it is advisable to always set out the work, fitting any broken portions together so as to find out the best method for the line of welding. Then with a piece of chalk mark off each mitre, thus saving time when again trying the pieces together.

In the preparation for welding all lifting arrangements must be fixed quite handy and everything else got ready so that the movements which will be required can be carried out with ease during the process. A little foresight will enable the operator to see what is actually needed. Any delay or bungling through inadequate provision of what is necessary may entirely upset the welding operation with serious results to the work. Time spent in thinking and planning out all that is required for the job will certainly pay in the long run.

A shortage of gas or a stoppage to charge the generator or to attach another cylinder denotes a want of thought in carrying out a proper job.

The sketches of joint preparation (Figs. 32 and 33) illustrate the various methods that can be applied in acetylene welding as follows.

No. 1 shows the best method for thicknesses up to $\frac{1}{8}$ in. This arrangement allows the edges that are opened up

at right angles to be melted down and to act as the filling material.

No. 2 shows two edges butted together, but this plan

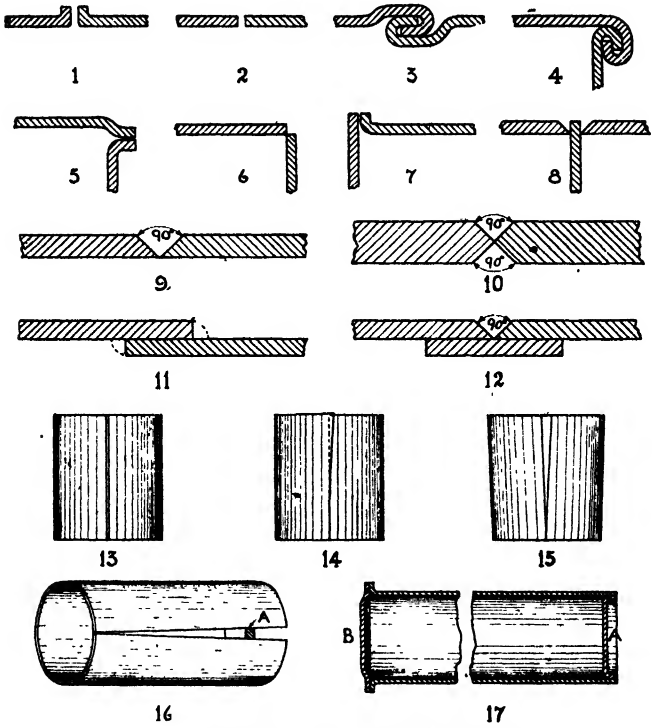


FIG. 32.—JOINT PREPARATION

should never be attempted on thicknesses greater than $\frac{1}{8}$ in. unless the operator is exceptionally skilled.

No. 3 is a folded or grooved joint for thin sheet, and needs very little welding. This, if hammered after a thin line of metal has been deposited, will make a good tight strong joint.

No. 4 is a grooved joint which takes the form of what is sometimes called a " knock-up," and is used where square or other corners are required to be made in sheet metal work. This after welding makes a very firm joint.

No. 5 shows a flanged joint used occasionally in connecting together plates in tank work.

No. 6 shows the fixing together of the square edges of two plates to form a right angle, the weld metal being deposited right down the corner.

No. 7 is a sketch of another method of forming a flanged joint for a tank.

No. 8 explains how a Tee section can be built up, the two side plates being Vee'd, the centre wedge being unprepared.

No. 9 shows the method of a single Vee to form a gutter or channel of 90°. This should be applied to thicknesses up to about $\frac{1}{4}$ in.

No. 10 is the double Vee which should be applied where the work can be welded at both sides of the plate, double Veeing obviating the necessity of making a very wide single Vee.

No. 11 is the ordinary lap joint which when welded should be practically equal in strength to that of the plate of which it is formed, and is, of course, stronger than any form of riveted joint.

No. 12 gives details of a strap joint for work which requires to be strengthened. The strap may also be formed by the angle or Tee iron, or any other required shape or design.

No. 13 illustrates the wrong method of preparing thin plate for welding, where no allowance is made for expansion or contraction, and

No. 14 shows the result of welding No. 13, causing an overlap as seen at the top of the sketch.

No. 15 shows the proper method of fastening the two edges of sheets with the necessary allowance for contraction.

In this case the welder commences at the closed end and gradually works in the direction of the open end.

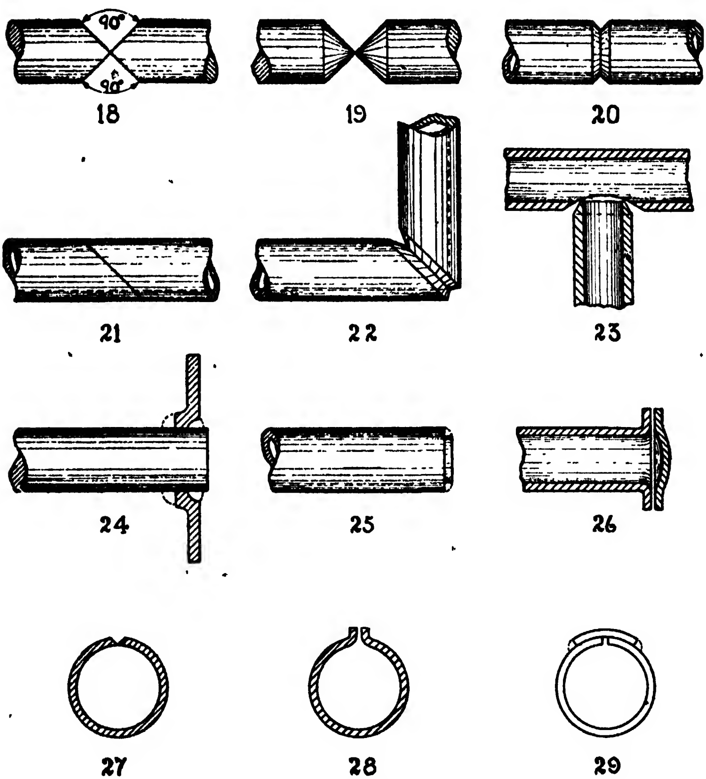


FIG. 33.—JOINT PREPARATION

No. 16 illustrates the same arrangement as No. 15, and applies to tanks or cylinders. The amount of opening depends upon the diameter and length of the tube which is best found by practice and often varies according to

the skill of the operator. A joint in larger tanks can be wedged open as necessity arises by an assistant with a bar, instead of with a wedge as shown at *A*. When a wedge or bar is used they should be manipulated to suit the movement brought about by the flame as it proceeds along the line of weld. If careful examination is made during the welding process it will be noticed that a continual closing movement takes place along the joint so long as the heat is applied. The opening of the joint at the commencement of welding is, of course, to allow for this gradual closing, so that by the time the job is completed the article will have attained its correct shape without leaving any defects or distortions.

No. 17 shows the best method that can be applied for welding the ends or top and bottom of a tank. The end *A* is prepared and welded in first, the flange end being adjusted from the open end *B* of the tank as welding proceeds. The end *B* is then welded on by the method shown, this arrangement helping to overcome the strain or possible distortion and needs no adjustment during the process. A little practice will enable the operator to become quite expert in the use of this method for welding up tanks.

No. 18 shows the method of preparation for a solid round bar forming a double Vee. This Vee it should be noticed is chisel pointed, and must not be cone pointed like a centre punch as shown in No. 19.

No. 20 shows the method to be adopted for welding a pipe or hollow bar. This is Vee'd to form a channel of 90°. When welded properly it makes a strong joint which, if necessary, can be reinforced by additional metal.

No. 21 shows the method of sawing through a pipe to form an angle or mitre. If it is required to form a right-angled bend the oblique cut is taken at an angle of 45°, the two pipes after being cut and mitred or Vee'd will, when reversed, form the right-angled joint shown in No. 22. A pipe elbow of any other angle can be formed in exactly

the same manner by taking the oblique cut on the pipe at half the angle of the required bend or elbow.

No. 23 shows the method of forming a Tee pipe by fastening a branch into a main. The hole in the main pipe can be cut by the oxy-acetylene process, but care must be taken to mechanically remove all oxide previous to welding, or otherwise the weld will be defective.

No. 24 shows a method of welding a flange on to a pipe, the flange being prepared in the lathe. In this case it is only necessary to just clean the end of the pipe. The flange if necessary can be reinforced at the back.

No. 25 shows the method of blanking or stopping one end of the pipe, a piece of circular plate being fixed just inside the end of the pipe and then welded around as shown.

No. 26 shows how the end of a pipe can be stopped by first flanging the edge of the pipe and then fastening a blank as shown.

No. 27 shows the single Vee preparation for a thick cylinder or bush.

No. 28 explains the flange or lap preparation which, of course, requires no Veeing.

No. 29 shows the method of laying on a butt strap for reinforcing.

There are many other methods of jointing which the welding operator will be able to devise to suit particular jobs as he gains experience. It will also be worth while to examine the methods of preparation as laid down for electric welding.

Motion of Blow-pipe for Oxy-Acetylene Welding As Illustrated by Fig. 34

A. Is an excellent method to adopt for the welding of thin plate work, and if followed correctly ensures perfect penetration and leaves a beautifully finished wavy appearance.

The flame of the blow-pipe should be correctly adjusted

to as near as possible the neutral condition, leaving just the least flicker of acetylene at the tip of the apex or white cone. Assuming the metal to be welded is mild steel, a start should be made at No. 1 position, and as soon as the bottom of the joint is fused the blow-pipe should be lifted just a little. At the edge of the first circle the centre should be fixed for No. 2 circular motion, the blow-pipe being held steady each time until the bottom of the joint is seen, then the blow-pipe raised to allow the metal to flow together. Taking each circle separately as marked on sketch, the only motion in connection with same, therefore, is the raising and lowering of the flame. After a little practice this motion will be found to give good results both in fusion and finish.

B. This is a movement for thin metal when the joint is Vee'd. The quicker the metal runs the quicker must be the travel. The movement is in the form of a spiral which can be made either from left to right or from right to left. Care must be taken so as to ensure the joining of the sides. The closeness of the spirals must be regulated according to the thickness of plate and flow of metal during the process.

C. Shows a larger sweep for heavy sections of metal, the travel being indicated by the arrow. The nozzle of the blow-pipe should be held at an angle of about 45° in the direction of movement, this having the effect of heating the metal at the point at which deposition takes place.

The filling rod should always be held near to the welding flame, which will keep the end heated and assist its melting as it is plunged in the bath of molten metal when required.

D. This is also a very good motion for metal of either light or heavy sections. The travel is really a series of half-circles with continued forward movement. This method enables the operator to complete the weld quickly, a point which should always be kept in mind, as a properly fused weld, made in the shortest time, will always give better results than one carried out at a slower rate.

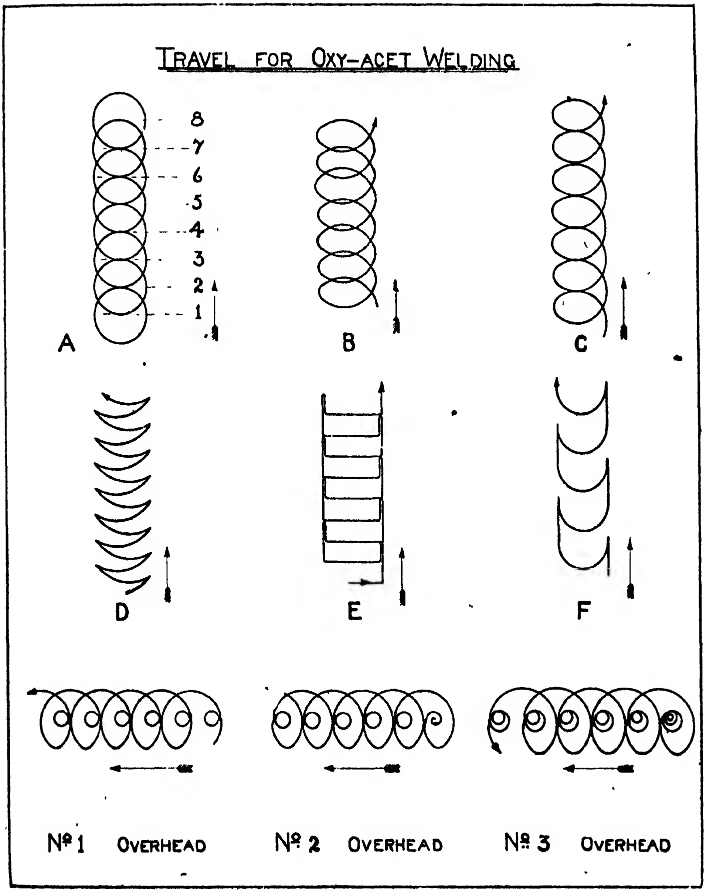

TRAVEL FOR OXY-ACET WELDING
8
7
6
5
4
3
2
1
A
B
C
D
E
F
Nº 1 OVERHEAD
Nº 2 OVERHEAD
Nº 3 OVERHEAD

FIG. 34

E. This is a forward movement which forms the three sides of a square during travel, the flowing metal following the flame, thus enabling the operator to keep the width of Vee to its original size. The tendency of the inexperienced welder using motion *D* is to widen the mouth of the Vee, thus upsetting the structure of the metal at each side as well as spending more time than is necessary.

F. This "fish-hook" form of travel usually gives very good results in practice. It has the advantage of protecting the size of the Vee from being impinged upon unduly by the flame, and it also enables the operator to complete the filling up of the Vee with greater speed together with a minimum amount of heat.

Overhead Welding. Diagrams 1, 2, and 3, Fig. 34, show the kinds of travel that can be adopted in the case of overhead work. Welding of this description with the blowpipe is much more difficult than with the electric arc. To overcome the pull-down of gravity upon the molten metal is rather a difficult task for the operator when he first tackles this kind of work.

The sketches show the motion which will give the greatest heat in the centre and the least at the outsides, by the loop movement, which is the partial solution of the problem of making the metal flow overhead and at the same time adhere, which it can only do by capillary or self attraction.

To become a good welder it is necessary for the operator not only to get a good deal of practice, but to develop his imagination so as to picture in his mind the results that are likely to take place from various kinds of actions. The welder who has mental power developed to form pictures of the results which will follow from certain movements, will find a good deal of his work very much simplified. Unless the welder is a quick, accurate thinker, a good many risks will be taken and many failures follow. A good welder should automatically know the kind of

movement of the blow-pipe which will give the most successful result on any particular kind of job.

The motions illustrated by diagrams 1, 2, and 3, Fig. 34, are all arranged so as to give the greatest heat in the centre first, then looping round to guide the metal to where it is required.

The greater the heat necessary in the centre, the greater the number of small circles the blow-pipe will have to make; this can be seen if diagram No. 1 is compared with diagrams Nos. 2 and 3. If the blow-pipe was held steady, instead of gyrating, the metal would fall away as soon as it got to the molten condition. The main point, therefore, is to remove the flame before the metal forms a large drop upon which gravity can act with sufficient force to overcome what is called the capillary or surface tension of the liquid metal. Therefore, the flame of the blow-pipe should generally lick the metal with a light sweep so as to enable it to remain in the position in which it is required.

With careful thought and steady practice there is no reason why any persevering operator should not become a proficient welder, even in overhead work.

There is no need to slavishly follow the kind of travels laid down, the information given simply being to guide the operator in his early work, after which he should build up such methods as suit his own personality best.

CHAPTER X

PRACTICAL HINTS IN CONNECTION WITH OXY-ACETYLENE WELDING

Explosions. There is no danger whatever of an explosion if ordinary common sense is exercised in the manipulation of the plant and the precautions laid down in the chapter on explosions are carefully followed.

Generators. These need systematic attention and overhaul not only from the point of view as a measure of safety, but to get the best results from their use. A good plan to follow is to have a log book or sheet, and to jot down from time to time the cost and date when anything is done, such as when the generator is dismantled, thoroughly cleaned out and examined, and when anything else is examined, put in order, etc.

The outlet pipes from the charging chambers should be periodically inspected and kept clear, for if the sediment is allowed to collect and these pipes become choked, the results might be serious from the point of view of bursting the carbide chambers.

The greatest care should be taken so as to have all joints and connections made perfectly tight, as in doing this a very considerable measure of safety will be ensured. Should any joints leak these should be stopped at once. Naked lights should never be used near the generator in case there may be leaky joints. A close examination by the " sniffing " process is usually sufficient to locate any escaping acetylene.

Should the generator be exposed to the open weather in the winter time it is always best to completely empty the tank of water overnight in case of freezing. If the water in the generator should happen to freeze, heat should

never be applied other than in the form of steam or boiling water. On no account should a flame or fire be used to thaw a generator.

When commencing to use a generator the greatest care should be taken to see that all air is removed from the spaces into which the acetylene will be charged. This can usually be done by the opening of a small cock which is fitted on to generators of any size, so that care should be taken to see that this cock is open when the acetylene is commencing to be given off from the carbide. Makers of generators always supply full directions with their plant, and these, of course, should be carefully followed. Neglect of these precautions may not only endanger the life of the operator but also the lives of others. Even after all care has been taken a certain amount of air will be present in the connecting pipes, etc., when the blow-pipe is about to be used, and this air should be got rid of before commencing to weld. It is just as well again to mention that air, together with a small percentage of acetylene, forms a very explosive mixture.

The carbide charging chambers must never be completely filled, as the carbide, when it comes into contact with water, expands considerably during decomposition. Therefore, to allow for this expansion the chambers or cages should not be more than half filled. Chambers usually have a drain cock on the bottom side to get rid of any surplus water in the chamber, or on some generators the chambers are fitted with doors at each end, which allow the operator to swill them completely through with the hose pipe. This type of chamber is much to be preferred to the single ended cylinders.

Purifier. As acetylene when generated from carbide contains impurities which affect the quality of the weld, it is essential that the gas should pass through some form of purifier so that a large proportion of the impurities may be removed.

As a measure of precaution generated acetylene should be regularly tested and a note of the result, together with date, recorded on the before mentioned log sheet. To test the gas a small piece of blotting paper should be saturated with a 10 per cent solution of silver nitrate, the acetylene being allowed to blow on this prepared paper. If after a few seconds exposure the paper turns black the gas will be certain to contain deleterious impurities. If, on the other hand, it remains white with little change in colour, the gas will be sufficiently pure for welding purposes. At any rate, the rapidity with which the prepared blotting paper becomes darkened can be taken as a measure of the quality of the acetylene.

Purifiers are usually fitted to all good generators, these being cylindrical in shape and of such dimensions as to suit the size of generator.

The impurities in the gas can only be removed by chemical means, the purifying material, of which there are several kinds on the market, being of such a nature that it chemically re-acts upon the impurities in the gas, thus trapping same in their passage from the generator to the connecting pipe.

The purifier needs regular attention, and when the acetylene is shown to contain impurities by the test mentioned, the purifying material in the generator should be changed. A definite quantity of the chemical substance used is supposed to purify a *certain* volume of acetylene, but a little practice together with regular testing will show how often the purifying material needs changing. Some of the substances which are sold for purifying purposes can be used over and over again by allowing them to be exposed to a dry atmosphere after being removed from the purifier, but careful tests should be made in the use of material of this character before placing complete faith in its usefulness.

If the purifier gets flooded with water care should be

taken to see that there are some available means for readily removing same. Also, tests should be made to see that the gas passes as freely as is convenient with cleansing through the purifier.

Working Conditions. It is essential that all the important parts of a generator, cocks, pipes, etc., are kept clean and in proper working order. Full carbide drums should be stored in a cool place, and never on any account be allowed to stand in moisture or in a damp position. Drums that have been opened should be completely emptied of the carbide, the portion not immediately required being stored in a drum with a closed top. Hermetically sealed drums for this purpose can be readily obtained—they are usually fitted with double lids to exclude the atmosphere; these drums should be kept in a cool and dry atmosphere standing on a piece of skeleton timber 3 or 4 ins. from the ground to allow for the complete circulation of air about same. It should be remembered that any generation of acetylene through dampness being allowed to get inside the drum and then closing same after might result in a disastrous burst. When drums are emptied of the carbide it should not be forgotten that there always remains a percentage of acetylene which is liable to cause an explosion if a flame is placed near it. Therefore, before the drum is thrown out, as a measure of safety all the gas should be removed by filling the drum to overflowing with water, thus driving out any gas that may have been present.

When the charging chambers of a generator are cleaned out the greatest care should be taken with the residue; this should be completely neutralized by being well flooded with water before it is thrown away. Unspent carbide getting into drains, sewers, or other places may cause a very serious explosion or fire.

Hydraulic Back Pressure Valve. This needs daily attention under ordinary working conditions, as it should always be borne in mind that the safety of the operator

and others depends upon it being in proper working order. Diagrams of a valve are shown in Figs. 27 and 28.

Before starting to weld the valve should be tested as follows:

Close cock on pipe from generator at *A*, and open drain cock at *B*, and also blow-pipe cock at *D*. Pour clean water in over-flow pipe funnel *C* until the water is level with the drain cock *B*. Then close cocks at *B* and *D*. The water level now will be the same both in the body of the hydraulic valve and also of the tube *C*. Now open the cocks at *A* and *D*, and the valve is ready for use. The gas will pass down the tube from the generator and bubble up through the water as shown, and so on to the blow-pipe. When the gas is passing through the hydraulic valve the water will rise in the tube *C* as shown in Fig. 27, the height of the water in this tube above that of the valve level being the measure of the difference between the inside pressure and the outside or atmospheric pressure.

If a back-fire results, the inside pressure will be considerably increased, and part of the water will be forced up the tube to the generator, and so effectively cut off the generator from the oxygen supply; part of the water will be blown out through the tube *C*, thus allowing the pressure of the back-fire explosion to fall to that of the atmosphere. This action is explained by Fig. 28. After a back-fire the cock *A* should be turned off and the hydraulic valve refilled with water as previously explained. Providing the hydraulic back pressure valve is correctly made, and the water kept at the right level there will be no fear of a back-fire flame travelling to the generator.

The hydraulic valve should be periodically cleaned out and all sediment removed, in fact it is a good plan to empty it at least weekly, swilling the barrel out and testing the cocks to ensure that they are in good working order. Examination should also be made periodically to see if any parts of the hydraulic back pressure valve are corroded.

Copper pipes must on no account be used for conveying acetylene from the generator to the welding department. as copper and acetylene under certain conditions form a compound which is readily explosive. The main pipes from a generator should be of iron or steel, and should be of ample size.

The hose should always be of the best manufacture and preferably three-ply, as flying sparks or any form of carelessness will soon destroy an inferior make of hose. Clips for securing the hose to connections and blow-pipe can readily be obtained, these being far preferable to the use of wire and lend themselves to quick adjustment or change of blow-pipe, considerably lengthening the life of the hose.

Gas Cylinders. As several gases are now being compressed into steel cylinders to be used for industrial purposes it is advisable that those who use them should not only know how to differentiate between the cylinders that are in use but also how to carry out a simple test to distinguish one gas from another. The usual gases which are compressed and sent out in cylinders are—dissolved acetylene, hydrogen, nitrogen, oxygen, coal gas, carbon dioxide, argon, and compressed air.

Cylinders which contain inflammable, or fuel gases, as they are sometimes called, have the nozzles fitted with left-hand threads for the regulator, whilst the non-inflammable gas cylinders are fitted with right-hand threads. In addition there is usually a distinctive colour for the cylinders and regulator valve.

Dissolved Acetylene cylinders, in addition to having a left-hand thread on the nozzle, are larger in diameter than other cylinders, and are stamped with particulars of the contents. The regulators for these cylinders are painted red. If the gas is passed through a small diameter tube and a light applied the flame will be yellow and very smoky, depositing carbon in the form of flaky smuts.

The gas has a distinctive smell as compared with hydrogen and oxygen.

HYDROGEN cylinders are painted red, the nozzle having a left-hand thread, the regulator for same also being painted red. If this gas is blown through a small jet and lighted it will give a blue tint and no smoke.

OXYGEN cylinders are painted black, the nozzle having a right-hand thread. This gas by itself will not light, but if blown on to a glowing piece of wood or charcoal it will cause same to flare up and rapidly burn. It also differs from acetylene in having no smell.

COAL GAS cylinders are painted red, with a left-hand thread nozzle. The coal gas has a distinctive smell and gives a yellow flame with very little smoke.

NITROGEN, ARGON, and AIR cylinders are all painted grey, the nozzles being fitted with right-hand threads.

Nitrogen and argon are both inert gases, and will not support combustion, and if blown on to any burning or smouldering substance will not only retard the burning, but entirely stop combustion taking place.

Compressed air has no smell, and differs from oxygen in only very slowly supporting combustion, so that there should be no difficulty in determining the difference between compressed air and compressed oxygen.

To sort out a pile of cylinders of varied contents the best plan to follow will be first of all to separate those which have nozzles or sockets with left-hand threads, that is those which contain inflammable gases, and then to apply to each the requisite test. In the same manner the cylinders which have nozzles with right-hand threads can be tested so as to determine the contents of the cylinders.

Great care must be exercised in the handling of cylinders so as not to damage the nozzle threads. Should a cylinder be discovered with a socket thread damaged and difficulty experienced in attaching the regulator, no attempt should be made to alter the thread, but the cylinder should at

once be returned to the charging depot with a label attached stating that the thread is damaged.

Oil or grease should on no account be applied to any of the oxygen cylinder connections, neither should cylinders be allowed to stand where oil can splash on them or even drip from the bearings of overhead shaftings. It should be remembered that oxygen coming into contact with oil or grease may set up an inflammable mixture, and thus cause a fire.

The blow-pipe flame should not on any account be allowed to play near a cylinder, as contact of the flame with the steel plate may heat the latter to a sufficiently high temperature to cause weakness of the plate and danger from explosion, in addition to which any heating up of the cylinder will cause a rise in the temperature of the gas, and consequently an increased pressure. Care, therefore, should be taken not to allow cylinders to be placed in any position where they are likely to be treated in such a manner as to cause an increase in temperature in the cylinder plate or contents.

It is always a good plan to see that all particles of dirt or dust are removed from the inside of the socket of the cylinder before the regulator valve is screwed into same, as any dust or dirt bottled up in the nozzle may cause a stoppage in the blow-pipe.

The cylinder valve should not be opened suddenly, but the handle or lever generally turned so as to allow the gas to pass from the cylinder very gradually. It is as well to call to mind that the pressure inside a fully charged oxygen cylinder is 1,800 lbs. per square inch, and gas at this pressure rushing through the regulator is liable to damage the diaphragm of the valve and also the elliptical tube of the pressure gauge. Rather serious accidents have occasionally happened in connection with the latter through the elliptical tube bursting and shattering the face glass of the gauge. Hence, as a precaution, it is as well not to

stand in front of the pressure gauge whilst the valve is being opened. As an extra measure of safety it is a good plan to cover the glass of the pressure gauge with some fairly strong wire gauze. In many cases there is no need to use a pressure gauge at all, as the regulator is all that is needed for getting the right pressure to use with the blow-pipe, the pressure gauge being used only when it is necessary to find out the quantity of oxygen in the cylinder.

As previously mentioned, it is again useful in this case to keep a log sheet or book for entering the dates of receipt of full cylinders, with each cylinder's name, the date of empties returned, with their respective numbers. It is also advisable to arrange a place in the workshop or stores for full cylinders, and another for empties, and as the contents of each cylinder is used to mark the latter for transport. This arrangement saves time in handling.

Blow-pipes. Blow-pipes, it ought to be remembered, are not rough and tumble tools that can be used or knocked about in any form, but should rather be considered as instruments of precision, delicate in construction, and usually very carefully designed and made. The blow-pipe should be cared for by a welder with almost the same amount of care as an engineer usually bestows on a micrometer gauge. A first-class blow-pipe is liable to be made almost useless through rough or careless handling.

A proper mixture of the gases in the blow-pipe depends upon the exact relative size of the tubes or chamber of the blow-pipe, and any damage or dent into this may upset the balance of the mixture of the gases and cause the blow-pipe to become defective. Some operators use a blow-pipe in almost the same manner as a hammer, and are then surprised when it does not give the very best results. The blow-pipe should not be tapped on the welding table or the end of the nozzle carelessly rubbed on a fire-brick slab, neither should the blow-pipe be left lying about where there is danger of anything falling

upon it. A blow-pipe when not in use should be hung upon a hook and every other precaution taken to preserve its life. A well preserved blow-pipe is one of the factors that tend to the making of good welds.

The correct size of nozzle in relation to the thickness of the work to be done should always be chosen, and wherever possible on heavy work arrangements should be made for pre-heating, as this will not only save gas but save time, and give a better result.

Before commencing to weld, an operator should always make sure that there is sufficient gas to complete the work in hand, as a stoppage when a job is in progress may mean serious results.

The apex of the cone of the outer flame must not be allowed to come into contact with the molten metal, as this will result in oxidization. This part of the flame should be kept just clear of the weld area, the metal being allowed to flow without being forced by licking with the apex of the cone.

Adjustment of Flame. The acetylene tap should be opened first and the gas lighted, the oxygen should then be turned on and the pressure regulated according to the thickness of the metal to be welded. As the acetylene gas is usually in excess the resulting flame will be of a reducing character, which means that there will be rather a long tail flirting out from the point of the white cone. The acetylene tap should then be closed a little so as to reduce the length of the tail. As the nozzle of the blow-pipe heats up it will be found that the flickering tail at the point of the white cone gets less and less on account of a slight enlargement of the hole in the nozzle due to expansion through heat. This slight enlargement of the orifice will allow a little more oxygen to pass through, and thus still further reduce the length of the tail on the white cone. Care, therefore, should be taken to see that the blow-pipe flame is correctly adjusted after the nozzle has been heated

up to the normal temperature of working. When in this condition just a little flickering will be observed at the tip of the white cone, thus indicating that there is the slightest possible excess of acetylene. On no account should there be an excess of oxygen, as this will inevitably result in an oxidized weld. A little practice will enable the operator to find out very quickly just the right size of white cone which will give the best results. In the welding of cast iron, aluminium, brass, and copper, care should be taken to see that the white cone flame has a longer tail indicating a distinct excess of acetylene, this being necessary in dealing with metals which in the molten state have a great affinity for oxygen.

To obtain the best results in the welding of steel the metal should be perfectly clean, all scale or oxide being mechanically removed, as any included oxide in the weld will inevitably cause same to be defective.

It is not necessary to use a flux for the welding of mild steel or wrought iron, but care should be taken to see that the filling rod is of the best quality. (*See* chapter on Rods and Fluxes.)

Having properly prepared the joint the welding can now proceed. The nozzle of the blow-pipe should be held at an angle of about 45°, and moved in the direction away from the operator, the filling rod being kept in the vicinity of the outer flame cone so that at any moment it may be added to the weld as required.

As soon as the metal begins to fuse the travel should be regulated according to the flow of same. On reaching the end of the joint, if trouble is experienced in building up the latter through the tendency of the metal to blow away, the blow-pipe should be raised and instead of pointing at 45° the nozzle should be held almost parallel with the work ; in this way metal can be deposited and the joint finished in a shapely manner. Notice should be taken of the fact that once the metal begins to flow it will follow the flame,

but great care should be taken that the feed metal does not flow over the joint without being fused to same, this, unfortunately, being a very common defect in joints. A welder should make certain that the metal of the body, together with that of the feed wire, are completely fused together. Some operators have a tendency to incline the blow-pipe tip more to one side of the Vee than the other, resulting in one face being fused down to a slightly greater extent than the other. This is a point which should be carefully noticed by the operator so as to make sure that there is complete fusion over the two faces of the Vee.

HAMMERING OF WELDS in wrought iron and mild steel should be carried out wherever possible, for if done properly it will certainly improve the character of the joint. The fused metal in the joint will, of course, have the properties of a cast or unworked metal, and if it is desired to have the property of toughness at the joint the metal should be hammered whilst in its hottest solid condition, the hammering being left off before the metal reaches the dull red state. Again, if it is at all possible it is as well to anneal the joint to remove any local strains, and also to refine the grain of the metal, which will give improved ductility.

Whilst welding proceeds the operator should not forget to keep his eye on the blow-pipe flame to see if this requires any adjustment, either through a fall in pressure of the acetylene or through the nozzle of the blow-pipe getting somewhat over-heated. In the latter case the acetylene should be completely shut off and the oxygen allowed to blow through slightly whilst the blow-pipe tip is dipped into cold water. The blow-pipe can then again be lighted up and the flame adjusted as required. Some thoughtless operators adopt the objectionable practice of dipping the hot blow-pipe into the generator water; this method of cooling should be avoided.

If a splash of molten metal enters the nozzle and causes a stoppage to the flow of gas, the gases should be immediately

shut off and the tip cooled as before mentioned. If the contraction set up by cooling does not get rid of this obstacle a very soft copper wire should be used to clear the orifice. On no account should an instrument that is formed of hard material be used to clear out the orifice, as this might increase the size of the hole, and result in upsetting the balance in the mixture of gases.

An operator should always make certain that the acetylene tap on the blow-pipe is closed whilst cooling is taking place. Hot welded pieces should not be left near the welder or the vessel of water, as this may cause ignition if there is the slightest leak of acetylene. When the blow-pipe is not in use the valves for both gases should be turned off, even if welding only ceases for a few minutes. If the plant has not to be used for an appreciable length of time a better plan is to completely shut the valve on cylinders or hydraulic pressure valve.

Cast Iron Welding. The proper welding of cast iron can only be accomplished successfully when thought and care are exercised. The usual complaints against cast iron welding are that the material is unworkable, contains pin holes, blow holes, hard spots, is porous, and also that welds very commonly crack either when cooling down or when the welded part is put into service.

With the ordinary cast iron parts of machines which get broken there is no serious difficulty in making a proper joint if the welding is carried out on correct lines.

The joint should first be cut away and thoroughly cleaned to allow for the welding in of the filling rod. The best kind of ferro-silicon rod and flux should always be used (*see* chapter on Rods and Fluxes), because the composition of the rod and flux play a most important part in producing a weld which is not only strong, but is as near as possible of the same composition as the cast iron being welded.

The blow-pipe should be of the correct size and the flame so adjusted as to be of a carbonizing character, that

is it should have a tail at the end of the white cone showing that an excess of acetylene is present in the flame. The tip of the white cone should not touch the molten metal, as this will cause the joint to be burnt, at the same time upsetting the balance of the carbon in the cast iron, causing pin holes and hard spots which will make the metal difficult to work.

Blow holes in the metal are sometimes caused by the poor quality of cast iron, and they can also be set up by the oxidizing of the carbon in the cast iron, causing bubbles of gas which cannot get out of the metal before solidification. Care should be exercised not to allow the added metal to drop into the bottom of the Vee, or not to be added in drops at any time, as this is also inclined to leave a cavity or to form a blow hole.

It is only necessary to use a small quantity of flux to dissolve and remove the oxide film, any addition to this quantity serving no useful purpose. To apply the flux the tip of the filling rod should be heated and dipped into the powder and then brought to the molten metal, this being quite sufficient to do the work of chemical cleaning. It should be seen that each side of the Vee has an equal amount of heating during the manipulation of the flame, so as to ensure perfect union of the added material right across the weld. As the flux melts down it should be allowed to run before the molten metal, in this way retarding the formation of oxide and at the same time keeping the flux residue from being trapped into the weld.

The nozzle of the blow-pipe should be held at an angle of about 45° pointing in the direction of travel. As soon as the bath of molten metal on the weld is procured care should be taken with regard to the proper motion of the flame. The tip of the rod should be put into this bath, and with the half circular motion the flowing metal carefully puddled. If this method is followed no blow holes should result but a perfect weld be obtained, providing, of course,

the flame of the blow-pipe has been properly adjusted. If oxide is allowed to be dissolved or trapped in the weld this, after cooling, will cause a series of pin holes to show up on the surface, and also give a weakened structure in the body of the metal, and possibly cause a leak or "weeping" if the work is to be used for water-tight purposes.

Hard Cast Iron Welds. Unworkable welds which are difficult either to machine or chip are caused through—

(1) Neglect in pre-heating.
(2) Too rapid cooling.
(3) Wrong flame adjustment.
(4) Use of flame cone in wrong position.
(5) Inferior kind of ferro-silicon rod.
(6) Spongy or oxidized cast iron material.

Cast iron generally is one of the easiest metals to weld when the work is carried out by a practised welder, but it requires expert skill and a fair length of practice before an operator can tackle most jobs with confidence.

Uniform pre-heating of the job is essential for successful welding of cast iron, as this serves the double purpose of minimizing trouble through expansion and contraction strains, and also the more economical use of oxygen and acetylene. Re-heating and slow cooling are also of very great advantage, as this stops the carbon in the cast iron forming the very hard carbide of iron, the slow cooling allowing the structure of the cast iron to settle down to the soft graphitic form.

The flame should be adjusted so as not to give an excess of oxygen, and it should also be used on the molten metal so that the inner cone does not come into contact with the weld.

For the best results a ferro-silicon rod should be used which contains the correct amount of silicon, besides also being generally of good quality.

Cast iron water pipes or parts of pumps which have

become graphitic will be found exceedingly difficult to weld, the filling material not firmly jointing the body of the article, the weld in use very quickly breaking away.

Cast iron articles, such as furnace pots, annealing pots, etc., which have been heated a great number of times and become oxidized in between the grain boundaries, will be found impossible to weld successfully.

Wherever possible it is a good plan to reinforce castings along the line of weld, as this, of course, adds strength to the structure, and in many cases is no disadvantage to the shape or use of the article.

Should the work not allow for reinforcing, the greatest care should be taken to make a perfect weld, this being executed as quickly as possible to avoid oxidation. The instant the filling material is placed in, an old file should be used to scrape away the surplus metal before annealing the work. This removes the hard carburized skin, and also saves considerable time in minimizing the amount of final dressing.

Malleable Cast Iron. This material is cast iron, which through a suitable process has been partially decarbonized from the surface or skin to some distance below same, the depth of decarbonization varying according to the length of treatment and the thickness of the casting. It is this variation in the composition and structure of the malleable casting which causes not only difficulty in welding but which also gives such varying results. To make a successful weld in this kind of metal, not only is some thought required, but the exercise of great care and skill in manipulation.

Some operators prefer a steel filling rod, whilst others favour cast iron, and in some cases a bronze filling rod is used which really gives a brazed joint. It is impossible to guarantee a good weld in malleable cast iron by the oxy-acetylene process without first of all carefully examining the material which is required to be welded, as the

depth of decarbonization determines the method of welding and also the resulting quality of the joint so made. Generally, better results can be obtained in malleable cast iron by the use of the electric arc, this being due to the fact that the heat of the weld is much more local, the depth of penetration not so great, and as the operation is carried out much quicker there is not sufficient time for the graphite in the core to pass into the molten metal on the surface to form the hard carbide of iron on solidification.

As a rule, where the malleablized skin is very thin it is better in oxy-acetylene welding to use a ferro-silicon rod together with a suitable flux. On the other hand, with thin articles that have been well malleablized, a mild steel filling rod can be used with advantage. In any case, the weld must be executed quickly, and this should be followed by annealing or slow cooling if the joint is required to be soft.

If the joint in malleable cast iron is to be made by brazing no serious difficulty will be met with if the right kind of brazing spelter is used and the work carried out in a proper manner. The joint must be Vee'd in the usual way, and the flame of the blow-pipe adjusted so as to be of a slightly carbonizing character, the work being carried out in much the same manner as with the use of a ferro-silicon rod, except that the temperature needs to be somewhat lower. Each side of the Vee should be carefully heated up and the brass filling rod applied with the necessary flux. If the metal deposits in small globules or spots it can be taken that there is not sufficient heat. To obtain a good joint the metal should run freely but not at too great a rate. A brazed joint made in this manner can, of course, be reinforced to any thickness so as to give additional strength if required. It can also be machined or worked.

Filling Holes. Holes in plates or castings that have been drilled in the wrong position or have become elongated, or for any other reason require to be filled for redrilling

or smoothing off can best be closed up by the use of the electric process, but if no electric plant is available the best plan will be to fit in the hole a mild steel solid piece, making a Vee at each side and flowing the metal all round with the blow-pipe, using a filling rod of mild steel. Slow cooling after welding is essential if the metal is to be left in such a condition that it can be chipped or machined.

Welding Tanks. If a tank has to be repaired or altered the first thing to be done is to find out the purpose for which the tank has been used, so as to ascertain if anything has been left either on the surface of the plates or in the atmosphere of the tanks that will cause an explosion. Many accidents have happened and may still happen unless care and thought are exercised. If an explosive mixture has been in the tank the latter must always be steamed out and thoroughly cleaned, so as to ensure that nothing has been left in the tank that is likely to cause an explosion. Safety is, of course, the first consideration, and through the lack of a simple examination of the residue left in a tank either of the gaseous, liquid, or solid form, many serious explosions have taken place. The least consideration will show that if petrol or other inflammable vapour is left in a tank that is to have a hole cut in it or be repaired, a serious explosion may result from the application of the blow-pipe flame.

Welders at times experience difficulty in successfully welding a round or elliptical blank into the side of a tank, but with some little manipulation this can be done quite easily. First, the two edges of the plate should be cut to form a 60° Vee, then four pieces of welding wire tacked to support the blank in this position as shown in Fig. 35. The operator should start to weld at *A*, travelling around the top section to the point *B*, then recommence at the starting point *A* and travel around the bottom half to *B*. In this manner the pulls through contraction will be fairly well equalized, and the resulting job will be much better

than if the welder had travelled continuously around the blank.

The welding up of a complete tank requires some forethought, and the operator will find that a close study of the chapter which deals with the preparations of joints will be helpful.

To avoid subsequent disappointment the operator should think all round the job and mentally sum up what is likely to happen in carrying out the welding of the joints or seams. It is often the consideration of the little details which may make or mar a job. Where a tank is formed of plates with the top flange outwards and the bottom flange inwards, it is a wise thing to weld around the inside flange first, as the plates are likely to need a little adjusting due to the pulling set up by contraction, and as, in this case, one end of the tank is quite open, both sides of the plate can be readily got at if required. Even with the inside flange end it is advisable to tack for 7 or 8 ins. or so, as this will obviate a lot of adjusting once the continuous welding has begun. The top end of the tank with the outside flange can quite easily be welded after the plate has been tacked into position.

Welding of Copper. The welding of copper causes some operators a good deal of trouble, due to the fact that they altogether ignore some of its peculiar physical properties, one of the most important being its great power of conducting heat. Its melting point is considerably lower than that of mild steel, and considering this welders are sometimes surprised to find that it is much more difficult to melt down than steel, but this is due entirely to the fact that copper conducts the heat through itself at about eight times the rate that mild steel does, and it is this heat which rapidly passes away to the body of the copper which robs the joint of that which is necessary to bring it to a melting condition. This difficulty then can only be got over by applying heat at a slightly greater rate, and for this purpose a larger

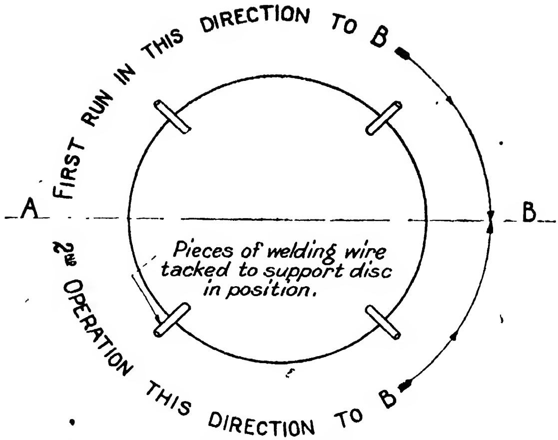


FIG. 35.—THE CORRECT METHOD OF WELDING BLANK IN A TANK

To avoid "after cracking" and making a successful job.

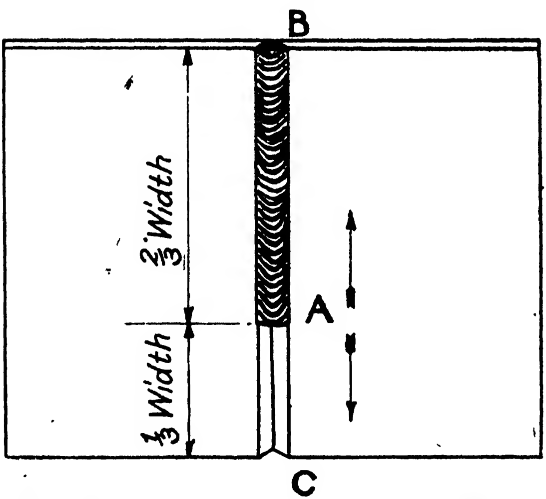


FIG. 36.—WELDING OF COPPER TO OVERCOME AFTER-CRACKS

(1) Commence at *A* and weld to *B*.
(2) Again start at *A* and weld to *C*.

sized blow-pipe should be used, as heat can then be transmitted to the joint metal at a greater rate than that at which it is dispersed.

A flux is required, but is not absolutely essential provided that the edges of the copper have been thoroughly cleaned, but if flux is used only a very small quantity is necessary. A special welding rod of phosphor-copper is required, and it is always advisable to procure rods of the best quality which have been specially manufactured for the purpose. The size of rod used depends upon the thickness of the material to be welded, general sizes are $\frac{1}{8}$ in., $\frac{3}{16}$ in., and $\frac{1}{4}$ in. diameter.

In learning to weld copper the operator should first try pieces of sheet of $\frac{1}{8}$ in. thickness, and about 2 ins. by 3 ins. long. The piece must be mechanically cleaned and the edges chamfered to form a Vee.

To obviate cracks in the weld great variations in temperature at different parts of the joint must be avoided as much as possible, as contraction strains are quickly set up and may be the cause of mischief. For a 3-in. length of joint as there would be on the pieces above mentioned, it is a good plan to start about 1 in. from the end, travelling along to the end, then commencing again at the starting point and welding along to the opposite end. (*See* Fig. 36.) By making several joints of this description and submitting them to severe bending and tensile tests the operator will soon train himself to become proficient.

CHAPTER XI

DON'TS FOR THE GUIDANCE OF OXY-ACETYLENE WELDERS

DON'T forget that oxy-acetylene plant is quite safe if all necessary precautions are taken and the usual instructions carefully followed. At the same time it should be remembered that the said plant in the hands of the thoughtless and careless may bring about effects equal to those of an infernal machine. (*See* chapter on Explosions.)

Don't forget to look after the safety of yourself and neighbour. Therefore, take no risks by seeing that every rule is carried out strictly to the letter.

Don't forget that a log book or sheet is an essential part of the appliance, and should be handy so as to be referred to at any time, and will thus minimize risk and do away with guess work. See that everything is put down in order. Cleaning of generator, hydraulic back-pressure valve, when purifier was last examined and charged, and the condition in which it was found. A list of the oxygen and D.A. cylinders and their distinctive numbers. All these entries will be of use to the man in charge of the plant.

Don't forget that the hydraulic valve must receive attention the first thing every morning, not only to adjust the water level, but also to occasionally flush the chamber to remove any sediment which may have collected.

Don't forget to have a bucket of water ready when welding, as it is a dangerous practice to cool the blow-pipe in an open type generator.

Don't forget when cooling the blow-pipe in water to close the acetylene valve, and to leave open the oxygen valve.

Don't lay small welded articles in their hot condition on

or near the water vessel, in case the acetylene blow-pipe connector may accidentally be left open and the gas fire as it is bubbling through the water.

Don't have an unnecessary amount of gas generating after the work is completed, but learn to gauge just when the water should be shut off, so that the product of after generation can be used economically.

Don't forget the generator needs periodical attention to keep it in a good state of preservation. It is a good practice to examine the generator once a month. It should be remembered that proper attention will always increase the life of the plant.

Don't forget the danger that lies in empty carbide drums. It is a good plan to empty the whole of the carbide from a drum into a properly constructed hermetically sealed drum, with a screw-down top. All empty carbide drums should be placed under the water tap and filled to overflowing; this will drive out any acetylene and obviate the danger of explosion through the dropping of a lighted match, or the playing of children with the drums when they are put out on to an open space.

Don't forget that the hermetically sealed drums should be kept in a cool dry place and raised at least 4 ins. from the ground on skeleton wood so that the air can circulate all round. This will remove any possibility of danger of water getting into the drum through a leak at the bottom and causing an explosion through the sudden generation of acetylene and consequent increase of pressure.

Don't forget to fix the generator in an out-house, and if possible protect it from the weather, and also arrange to have a good circulation of air.

Don't smoke near the generator, and what is more important, try and arrange to keep others from doing so. Fix up a notice to this effect in a prominent position, and see that it is obeyed.

Don't charge the carbide chambers of the generator more

than half full, so as to allow for the increase in volume as the carbide is decomposed and lime is formed.

Don't get alarmed if the water begins to syphon from the generator back to the charging chambers whilst recharging. To stop this take out carbide tray and throw a piece of carbide into the chamber, secure doors, and thus allow the gas generated to drive the water back. Allow a few minutes to elapse and then charge in the usual way.

Don't forget that the outlet pipes from charging chambers are likely to get choked if neglected, and this means an explosion if the generated gas cannot escape. Therefore, take great care to see that all pipes are kept clear.

Don't have any leaks of acetylene either on generator or near to same.

Don't, if there happens to be a leak, be so stupid as to use a light to try and locate it. Generally sense of smell is quite sufficient for the purpose.

Don't use copper pipes for conveying acetylene from the generator to the workshop. Copper at times has a nasty habit of combining with acetylene to form an explosive compound. Therefore, use iron pipes.

Don't have a generator that is on the small side. Remember that as time goes by and trade expands the generator will be too small for the work, resulting not only in waste but bad welding. It is better to always err on the large size when buying a generator.

Don't forget that generated gas is usually impure and needs purifying. The purifier, therefore, should have regular attention.

Don't forget to test the gas occasionally, and if necessary to take steps to change the purifying material.

Don't buy shoddy tubing because it is cheap ; it is less expensive in the end to get good three-ply tubing to withstand the pressure, handling and flying sparks.

Don't forget that both oxygen cylinders and D.A.

cylinders require handling with a little care, and this is especially so with regard to the treatment of the valves. It is as well to remember that an oxygen cylinder when fully charged has a pressure of about 1,800 lbs. to the square inch. There is, therefore, some considerable force behind this.

Don't stand oxygen cylinders near overhead shafting or anywhere else where oil may drop and come in contact with the valve or oxygen. Oil and oxygen make an inflammable mixture. Therefore, don't grease the threads of the oxygen cylinder valve or regulator.

Don't expose cylinders to the open weather, as this is neither good for them nor the valves of same.

Don't use regulators with pressure gauges. The elliptical tube inside under sudden pressure sometimes breaks, bursting the glass. This may result in serious damage to the operator's face or eyes. It is as well to have a special gauge for registering cylinder pressures when this is found to be necessary.

Don't have your face near any gauge glass front when turning on the oxygen.

Don't turn on the oxygen suddenly, but tap the key lightly with the hand, sudden pressure will soon put the regulator out of action, its mechanism being very delicate and not adapted for rough use.

Don't forget before opening the cylinder valve to have open both the oxygen valve of blow-pipe and the outlet valve from cylinder. This obviates any sudden pressure on the regulator diaphragm, and allows the gas to blow through into the atmosphere.

Don't use wire to secure the hose to blow-pipe, as screw clips can readily be obtained. This avoids damage being done to the rubber pipe, and at the same time allows of easy adjustment.

Don't forget to have hydraulic valve fixed in a place where it can be readily seen in case of back-firing taking

place. It is a good plan to have it fixed a little higher than the welding table.

Don't forget that the residue from the generator needs a special place, and this should be away from the spot where the operator is working

Don't forget that the residue should be completely neutralized by adding about ten times its own volume of water before committing it to the disposal dump. If necessary, it can be used for garden purposes, or for white washing.

Don't allow the residue to run into the main roadway, or even down a sewer, as serious explosions have occurred through acetylene being generated in the sewers, and this fired by the dropping of a lighted match or a cigarette end by a smoker.

Don't forget that the generator needs a good swill out with a hose-pipe occasionally, and re-filling with clean water.

Don't have an unnecessary amount of hose-pipe lying about the floor of the workshop, but see that it is kept from careless people trampling upon it.

Don't forget to have a place for everything, and see that everything is kept in its place. It saves time, worry, and bad temper, and also preserves the equipment.

Don't handle blow-pipes carelessly, or leave them lying about. Any alteration in the tube shape may upset the balance of the mixture and cause trouble. Always keep blow-pipes in special boxes when not in use, and have brackets fixed in suitable places on the wall for hanging up the blow-pipe when it is in general use. This prevents the possibility of knocking about and is also the means of saving time.

Don't use a steel or iron instrument to clear away any obstruction in the blow-pipe tip. If the obstruction is not removed after cooling tip, clean same out by the use of a piece of soft copper wire. Remember that any enlargement of the nozzle hole will upset the proper flow of the gases.

Don't forget that non-inflammable gases have right-hand threads on the cylinder valves, and inflammable gases left-hand threads.

Don't on any account tamper with the threads of cylinder valves, or make an adaptor if the regulator will not fit. If there is anything wrong return the cylinder to the charging depot with an attached label stating the nature of the trouble.

Don't attempt to force the left-hand thread regulator into an oxygen cylinder. This type of regulator is painted red, and should only be used for an inflammable gas cylinder. Be careful to use the regulator with the right-hand thread and that is painted black.

Don't dismantle blow-pipes and regulators unless you thoroughly understand the details of their working. If there is any trouble send them to people who specialize in this kind of repair.

Don't on any account allow cylinders to be exposed to the flame of the blow-pipe or any excessive heat. Remember that a rise in temperature means an increase of pressure, and also that a red-hot steel plate has about one-twentieth of the strength of a cold plate.

Don't neglect to have oxygen cylinders annealed every four years if they are your own property. This does not concern you if they belong to other people.

Don't attempt to make your own hydraulic valve, unless you fully understand what its functions are. Remember it is intended for your safety, therefore it is advisable to buy one from people who specialize in this class of article.

Don't forget that the proper preparation in some classes of work is the most important part of the job.

Don't forget to clean the surrounding surface as well as the Vee, or the heat may dissolve the oxide enabling same to mix with the filling material and thus cause a defective joint.

Don't attempt to rush a job through too quickly, or on

the other hand, don't have any unnecessary delay. No fixed rules can be given but both of these at times are detrimental to the making of good joints.

Don't forget to protect machined surfaces with graphite and oil if they are to be pre-heated, as this prevents the metal scaling, and thus spoiling these faces during the time they are in the stove or fire.

Don't stand cylinders in their working position when in the stove or fire for pre-heating, but turn them upside-down during this process until they are ready for welding. They should not be left on their sides either, as this may cause a distortion to take place.

Don't attempt to weld cylinders when they are too cold, or defects will be sure to result.

Don't, on the other hand, allow them to get beyond a dull red heat, as they begin to get near the point of collapse and distortion. See that cylinders are placed in stove upside down, resting on iron plate.

Don't allow rapid cooling after completion of the work, and this particularly applies to castings. It is sometimes advisable to return to the stove, re-heat and allow to cool in same. If a stove is not available the casting may be protected with asbestos or fine ashes.

Don't allow too much air for the stove, as it is advisable to have a yellow flame, and it is a good plan not to allow the flame to play directly upon the work but upon a fire brick bed, as this will disburse the heat and make the temperature more even. Slow heating is almost as essential as slow cooling to obtain the best results.

Don't forget that it is better not to use coke, but coal gas, or if at all possible use charcoal. If a smith's forge or hearth is handy it is a good plan to make a large fire on this, and after completing the work in the temporary fire this latter can be replenished from the hearth and in this way a more uniform heat obtained which will assist slow cooling.

Don't use a blast for pre-heating but only for obtaining a good fire, and don't use it at all if a good stove is available.

Don't forget to support the parts of aluminium castings which may collapse during pre-heating.

Don't allow aluminium flux to be exposed to the atmosphere for any length of time, as it is a deliquescent substance and will soon be converted into a liquid. Put out sufficient only for immediate use, keeping the remainder air-tight.

Don't adopt the plan of dipping the welding rod into a full tin of flux.

Don't forget to always protect the eyes from the strong light of the blow-pipe flame. Whilst the latter is not as dangerous as the metallic arc, the eyes need protection from the intense glare. Take care to select glasses of a suitable tint to suit your own eyes. Glasses either too light or, on the other hand, too dark, damage the eyes in course of time. Always keep spare goggles in case of accident.

Don't forget to see that the blow-pipe flame is correctly adjusted. A wrong type of flame means bad work. The gases should be adjusted to give a neutral flame for the majority of metals, but for aluminium, cast iron, and bronze, just the slightest flicker showing excess of acetylene is a good safeguard against the tendency of the oxidizing of these metals.

Don't allow the tongue or the apex of the flame to lick the metal, as it is much better to just miss making contact. This will keep down blow holes and reduce the danger of blowing the metal away.

Don't forget to aim at obtaining the proper motion of the blow-pipe, and at the same time remember that the metal when it once begins to flow will follow the flame.

Don't try to fill up a hole by just running in metal, but hold the flame steadily upon the hole, and when the metal begins to flow make a circular movement with the flame and the hole will disappear.

Don't get into a panic if a back-fire into the hydraulic valve takes place. Remember to shut off the gases at the blow-pipe ; secondly, shut off the acetylene to stop it flowing into the valve ; and thirdly, fill the hydraulic valve with water to the level of the bottom drain cock.

Don't put a No. 6 nozzle on to a No. 4 blow-pipe, or any other nozzle than that which is suitable to the capacity of the blow-pipe. If the blow-pipe is of a universal character there will be a range of suitable tips. In any case, take care to read the instructions given with any special make of blow-pipe.

Don't try to melt down and make to flow too much metal at one time, or blow holes are bound to be created. Deposit the metal a little at a time, and, most important of all, put it in the right place.

Don't forget to anneal alongside the line of weld if at all possible, as this tends to relieve the stress set up in the metal by the rapid change of temperature.

Don't clamp too tightly any portion of a job that is to be welded, as the metal must be free to expand or it will inevitably fracture.

Don't sprinkle the flux on the work. The heating of the filling rod and dipping into the flux will be ample for what it is required to perform. After a deposit has been made lift the rod and allow the metal to solidify just for a second, as this assists any gases to escape.

Don't forget to have by you a few tapered wooden plugs, as they come in very handy when castings or motor cylinders are to be tested. Long ones of about 4 ins. are the best with a gradual taper. The use of these will save making blank flanges or securing metal plugs, and in this way will save time and expense.

Don't attempt to weld or cut metal in a confined space where there is no circulation of air, as the products of combustion from the blow-pipe may cause suffocation. If work has to be done under these conditions a ventilating

fan must be fixed to cause proper air circulation. Even under ordinary conditions windows and doors should be open to keep the air as clear as possible.

Don't attempt to weld a perforated casting in the cold state, as the stress set up on the parts between the holes is very great. Careful pre-heating is essential if good results are to be obtained.

Don't make square or rectangular patches for welding if a round or elliptical shape can be substituted, as expansion and contraction strains in the latter cases are easily overcome.

Don't commence at one end of a crack and weld along the full length without carefully weighing up what the result will be. It is usually better to do the welding in sections so as to balance, as far as possible, the contraction strains on cooling. If, however, a crack is at the end of a plate the best plan will be to start from the inside and work along to the edge.

Don't forget that where a weld is made on a tank or boiler a few inches from a riveted joint that it is necessary to caulk the latter after welding, as the joint is usually open through expansion and contraction. If this is not done a leak will very often develop at the seam.

Don't ignore the fact that a welded casting through contraction rarely remains quite accurate in size and shape, but at the same time point should always be made of trying to obtain the very best results. For instance, sometimes a pulley or other castings that have had bushes or bearings after being welded are slightly out of true. In these cases it is advisable to machine out the housing and re-bush, or if the holes are small ones to fit a solid bush to the casting and bore the hole just where it is required.

Don't attempt to reclaim journals on armature shafts by the oxy-acetylene process, but preferably use the electric arc process. If the latter is not available then suitable protection should be placed over the winding to guard against the excessive heat. Asbestos moistened

with water is a good protective agent. Electric arc welding is more local than oxy-acetylene, so that for this protection is only needed against metal sparks which may fly on to the winding, and this can be protected by dry sheet asbestos.

Don't attempt to pre-heat a very large casting if only a small part is to be welded, the cost of fuel and the heat required will be very great. Weld the portion, and although the metal may be hard through rapid chilling, it can be ground down to the right size with a portable electric grinder.

Don't be disheartened when attempting to weld aluminium alloys. If chemical cleaning fails to break up the oxide film use some mechanical means in the shape of a steel or iron rod. A little patience and perseverance will get over the difficulty. Failure to remove the oxide will spell disaster to the welded joint.

Don't forget that although aluminium alloy has a lower melting point than cast iron, it has greater conductivity for heat, and also a higher degree of expansion. Hence, the need for special care so as to obtain the best results in welding.

Don't forget that metals such as aluminium, copper, etc., which are good conductors, need the application of a greater quantity of heat (not higher temperature) than metals of the same thickness that are bad conductors. The extra amount of heat is simply required to make up for the greater losses from conduction and radiation.

Don't forget that "welding" is almost a casting process, the Vee forming the mould. The result, therefore, will be in proportion to the quality and condition of the metal run into the mould. A thorough study of the metallurgical side of welding is well repaid in the knowledge of how best to treat the metals that are being used.

Don't be content with mediocre results, but aim to become as efficient and capable as it is possible to be, and this can only be done by obtaining as much useful knowledge as can be acquired, together with good practical training.

CHAPTER XII

THE ATMOSPHERE

Gases Used by Welders

Seeing that nearly all welding operations have to be carried out under atmospheric conditions, it is worth while paying some attention to the effect which the air has not only upon welds but upon the carrying out of the process of welding itself.

It is rather a significant fact that the second chief constituent of the air is at one and the same time the welder's friend and his greatest enemy. For whilst oxygen is, of course, the gas which is absolutely essential to support combustion in blow-pipe operations and is thus the friend of the welder, it is perforce his greatest enemy in as much as welding operations have to be carried out in an atmosphere which contains about 21 per cent of this element, and which is always making strong efforts to combine with the molten metal, and thus interfere with the good quality of the welder's work. The same, unfortunately, holds good not only for gas welding but also for electric arc welding, as without due precautions, in the latter case as with the former, the material of the weld readily becomes oxidized. In electric welding, also, not only does the oxygen of the atmosphere tend to upset the welding material, but the nitrogen as well, this latter element when dissolved tending to cause electric arc welds to be brittle.

The Atmosphere. Generally speaking, the atmosphere is an envelope of air about the earth some 50 miles or more in height, of decreasing density as the height increases, and what is called "atmospheric pressure" is nothing more or less than the weight of this height of air pressing

upon the earth's surface, the average pressure being 14¾ lbs. per square inch, but this for practical purposes is usually taken to be 15 lbs. to the square inch. The atmospheric pressure may be roughly read on the barometer, taking 2 ins. to equal 1 lb., thus if barometer reading equals 30 ins. the pressure equals 15 lbs. This pressure may not seem very much as compared to steam pressure, etc., but when considered as acting all over the surface of the human body it will total to somewhere about 11 tons. This is a somewhat surprising result, but as the pressure is completely balanced on all parts of the body, its effect is, of course, not felt.

A very simple experiment to bring home to one the effect of atmospheric pressure is to make a tin can of about a 6-in. cube, fixing at one corner a small conical pipe to take a plug. About a tea-cupful of water should be boiled in the vessel for a few minutes, and as soon as the steam is blowing out the source of heat removed and the plug put in the tube. The vessel should then be bodily plunged into a bucket of water, taking care that it is entirely submerged, when it will be found that the faces of the tin cube will be completely crushed in, due to the steam inside the vessel having been condensed and forming a vacuum, thus allowing the total atmospheric pressure to come into play upon the surface of the vessel.

In carrying out this experiment it will be an advantage to have a wooden plug 8 to 10 ins. long to push into the inlet, so that by taking hold of this the vessel can be put under the water without any danger of the hand or fingers being pinched, through the collapse of the vessel, if otherwise held.

A simple calculation will show that the total pressure on the six faces of this small cube at 15 lbs. to the square inch will work out at 3,240 lbs. An experiment such as this should at once bring home to the welder the importance that atmospheric air plays in all welding operations.

The atmospheric pressure of 15 lbs. to the square inch, it should be remembered, is always attempting to press upon the molten surface of a weld, and except it is stopped from coming into contact with the metal by the intervention of some form of non-oxidizing gas or vapour, it will certainly form an oxide, this oxide often at the same time being dissolved into the molten metal.

Fairly accurately, the composition of the atmosphere can be taken as—

Nitrogen	78·1	per cent by volume.
Oxygen	21	,, ,, ,,
Argon	·9	,, ,, ,,

The air also contains a small percentage of carbon dioxide varying from ·01 per cent to ·04 per cent, but in rooms this amount is very much increased. There are also traces of water vapour and ammonia in the atmosphere, and very small percentages of other elements and compounds, which affect the work of the welder to only a small degree.

It is of interest to note that air goes into the liquid form at 191° C. below zero, or under a pressure of about 575 lbs. to the square inch it will pass into the liquid form at 140° C. below zero. This property is taken into account in the making of oxygen by the liquefaction of air, as oxygen and nitrogen passing into gases from the liquid form at different temperatures allows the method of distillation to be adopted and the two gases separated.

The table given at the foot of page 131 shows the temperatures and pressures at which the gases named go into the liquid form.

From the table it will be seen there is a distinct difference in the temperatures at which oxygen and nitrogen will pass from the liquid to the gaseous form. Hence if the temperature of liquid air is allowed to rise a little it will be seen that nitrogen will first distil over leaving the oxygen to pass into the gaseous form at a higher temperature.

Nitrogen generally acts as a diluent to the oxygen, simply retarding the oxidizing influence of the latter gas. Whilst nitrogen usually acts beneficially in diluting oxygen and thus retarding its oxidizing tendencies, at the same time, it is a distinct disadvantage to have this retarding action by the presence of nitrogen in oxygen that is to be used for cutting purposes.

The oxygen of the atmosphere, it should be remembered, acts more rapidly on a metal as the temperature of the latter increases, and generally when a metal arrives at the molten state it is acted upon by oxygen most rapidly.

All kinds of efforts are made to stop the formation of scale or oxide on a metal as it is being heated, but this can only be successfully accomplished when the metal is either covered with some form of flux or is kept in a non-oxidizing atmosphere.

The loss, by the formation of oxide or scale, in the working of iron and steel from the time when it leaves the smelting furnace until it is converted into the finished article, is enormous, and any efforts in the direction of reducing this loss are well worth attempting.

The future of metal working should show great improvements in not only protecting the surface of metals when

	Temperature in degrees Centigrade.	Pressure in Atmospheres.
Hydrogen	− 220	15
Oxygen	− 118	50
Nitrogen	− 146	36
Air	− 140	39
Argon	− 121	51
Chlorine	+ 146	94
Carbon Monoxide	− 180	35
Carbon Dioxide	+ 31	77
Ammonia	− 130	115
Sulphuretted Hydrogen	− 100	92
Sulphur Dioxide	− 155	79

hot from oxidation, but also after they are finished. As the world's losses in metal through atmospheric corrosion runs into millions of pounds per annum, there is a big field of investigation open to find out ways and means by which these losses can be reduced.

Hydrogen. Hydrogen, like acetylene and coal gas, can be used as a fuel gas on account of the great affinity which it has for oxygen, and which, on combining with same to form water, gives out a large quantity of heat.

Hydrogen is the lightest of all known gases, being about one-sixteenth the weight of an equal volume of oxygen, as will be seen on referring to the table at end of book. It is a clear gas, being without odour, however, when given off from the surface of pickling baths it is usually mixed with acid vapour, the latter, of course, giving it a distinct odour.

By electrolysis water can be split up into its component parts of hydrogen and oxygen, this being one of the modern methods of obtaining both these gases for industrial purposes. Hydrogen, too, can be evolved by water vapour coming into contact with red hot iron, or the passing of water coated metallic articles into molten zinc and other metals, the oxygen of the water combining with the metals, the hydrogen being freed. Steam, also, is readily decomposed when passed over red-hot coke.

Hydrogen is also evolved by the action of various acids, such as hydrochloric and sulphuric, on metals.

Hydrogen can be stored over water as it is only very slightly soluble in same. For many years it was thought to be a permanent gas, but now, like all other gases, it can be liquefied when a sufficiently low temperature and high pressure is obtained. The temperature of liquefaction being about 252° below zero, and at about 6° lower it passes into the solid form.

When hydrogen is burnt in air or oxygen it gives an extremely hot flame, but, of course, not equal in intensity to that of the oxy-acetylene flame.

Being a reducing agent hydrogen plays an important part in connection with metallurgical operations, as it not only reduces oxide to the metallic form, but under certain conditions stops them from forming. Indeed, the mirror-like appearance of molten metal seen when using the oxy-acetylene blow-pipe flame in welding, is in a large measure due to hydrogen being present in the inner zone of the flame. It has been found, too, that metals in the presence of hydrogen can be readily coated or joined by a second metal, perhaps one of the best illustrations of this being what is known as the "Hyding" process of copper welding or coating, in which steel, even without having its oxide or scale previously removed, can be coated with copper if placed in a furnace after being coated with copper oxide and brought to a red heat whilst surrounded with hydrogen.

Hydrogen as a fuel gas can also be used with oxygen for cutting purposes, and it can be used for other blow-pipe purposes where a temperature is required somewhat less than that given by the oxy-acetylene blow-pipe flame.

Hydrogen, too, is peculiar in as much as it is the chief gas which is absorbed by metals, nearly all metals absorbing the gas under certain conditions. One of the simplest ways in which hydrogen passes into steel or iron is when these metals are cleaned or pickled in hydrochloric or sulphuric acid, quite a quantity of the gas being absorbed by the metal. The steel or iron, however, gives the hydrogen out again very quickly when slightly heated, and in some cases when allowed to stand for several days or if kept under the surface of water.

There is no disadvantage in welding for hydrogen to be absorbed in the steel, but rather otherwise, and, indeed, claims have been made that some welding wires have purposely had hydrogen added to them, so as to give a better result in the welding operation.

When metals have to be coated with zinc or tin, there

does seem to be a disadvantage in having hydrogen absorbed by the metal, as the gas tends to give out in the coating process, interfering with the combination of the coating metal and the base metal.

Now that oxygen is being more generally made by the electrolysis of water it should free a large quantity of hydrogen which ought to find some important metallurgical use, either as a fuel gas or in some form of reducing process.

Coal Gas. Coal gas with oxygen or air can be used in the blow-pipe for brazing and other similar purposes where a lower temperature is required than with actual welding. The composition of coal gas varies considerably, depending upon the amount of water gas that is added to it.

It is usually composed of about 50 per cent of hydrogen, about 30 per cent of hydro carbon gas, known as methane, about 10 per cent of carbon monoxide, together with small percentages of various other gases.

Petrol, Benzol, Benzine, etc. A number of volatile liquid hydrocarbons, such as the above, are also used as fuel vapours, as these when burnt with air or oxygen give fairly high temperatures and a large quantity of heat.

These liquids when vaporized give a very large comparative volume of vapour, which act in almost the same manner as the gas. For instance, one gallon of petrol will vaporize into about 30 cu. ft. of vapour. For blow-pipe purposes under certain conditions there is no doubt whatever that petrol, benzine, etc., can be made to serve a very useful purpose.

Oxygen. The common use to which the gas oxygen is now being put is rather surprising when it is remembered that it is only about 150 years ago since Priestley definitely discovered this gas as a constituent of the atmosphere.

In Nature oxygen is not only the most abundant but also the most widely distributed element, as it forms about 21 per cent of the atmosphere, and about 86 per cent of all

the water on the globe. About 47 per cent of the earth's crust is also mostly in the form of oxide of metals.

In the chemical laboratory it can be made in a variety of ways, the simplest of which is by adding to potassium chlorate one-eighth of its weight of manganese dioxide, and heating these in a test tube over a bunsen burner and collecting the gas given off from the heated mixture over water. But whilst the gas can be readily prepared in many of these ways, for commercial purposes they are altogether too expensive.

Although oxygen and nitrogen are only mixed together to form the atmosphere, the peculiar thing is that it seems almost impossible to separate them mechanically. Several attempts have been made to pass air through some form of filter which would separate oxygen from the nitrogen, but up to the present without much practical result.

The earliest of the successful industrial methods of producing oxygen was that known as Brin's, in which barium oxide is heated to a dull red in a current of air, when it is converted into barium peroxide by the chemical addition of oxygen. When heated to a still higher temperature the barium peroxide is changed back to barium oxide by the giving out of the oxygen formerly taken in. Thus by a reversal process of falling and rising temperatures oxygen can be produced. Several improvements have been made in the process, and many plants erected and successfully worked in different parts of the world. This process has, however, gradually fallen into disuse on account of the cheaper and better methods of producing oxygen by the liquid air process or the electrolysis of water.

Oxygen is a gas without colour, taste, or smell. Compared with air it has a density of 1·1056. At the average atmospheric pressure 11·84 cu. ft. weigh 1 lb.

Oxygen passes into the liquid form at a temperature 118° below centigrade, and at a pressure of not less than 50 atmospheres. Liquid oxygen is a light-blue transparent

liquid, and passes into the solid form at about 219° below zero. One volume of liquid oxygen is equal to about 782 volumes of the gas.

All substances which burn in air burn with greater intensity in oxygen, this being particularly shown up in the case of burning iron under the cutting action of the blow-pipe.

The amount of heat given out during the burning of any substance will be the same whether the combustion is carried out in air or in oxygen, or whether the action is slow or rapid. The temperature developed, however, will be highest in the case of the rapid combustion. The temperature of the oxy-hydrogen flame is 2800° C., and that of the oxy-acetylene flame 3300° C.

Oxygen is not very soluble in water, the latter taking up about 4 per cent by volume at 8° C. It has the rather remarkable property of being soluble by several liquid metals, thus, molten silver will absorb 22 volumes of oxygen, giving the same out again when it cools. This is also true of several other metals, copper and iron both dissolve oxygen probably in the form of oxide, this oxide alloying with the metal giving the latter quite different properties than when in the pure state. Most of the ordinary metals of commerce when in the heated state rapidly combine with oxygen to form oxides or scale. The smithy scale of iron having the composition of Fe_3O_4, which means 62·4 per cent of iron combines with 27·6 per cent of oxygen.

The oxygen of the atmosphere, through a process of what might be called slow combustion stimulated by moisture and traces of acid, also combines with the surface of metals, resulting in tarnishing or corrosion.

For use in welding, oxygen is put up in steel cylinders which contain 100 cu. ft. of the gas at atmospheric pressure, compressed usually to a pressure of 120 atmospheres which equals about 1,800 lbs. per square inch.

Acetylene and Carbide of Calcium. Acetylene was

discovered accidentally by Edmund Davy in the year 1836, and whilst it has been known and used in very small quantities for the last three-quarters of a century, it was not until quite recent years a method was found of manufacturing it in sufficiently large quantities to be of commercial use. It is also rather peculiar that the method of making carbide of calcium from which it is now generated was also discovered by accident in the year 1892.

Acetylene is a transparent gas somewhat lighter than air, 110 cu. ft. of the gas having the same weight as 100 cu. ft. of air. The following table shows the relative density and the number of cubic feet to the lb. of acetylene, and also of the more common gases—

	Sp. Gr. Air = 1.	Cu. ft per lb. of Gas.
Hydrogen	0·07	178·3
Coal Gas (average)	0·438	28·27
Ammonia	0·589	21·01
Acetylene	0·91	13·65
Carbon Monoxide	0·967	12·80
Nitrogen	0·973	12·72
Air	1·000	12.38
Oxygen	1·105	11·20
Carbon Dioxide	1·529	8·10
Chlorine	2·44	5·07

Acetylene is composed of carbon and hydrogen in the proportion of 24 parts of the former to 2 of the latter, which in the form of a percentage gives 92·3 carbon to 7·7 hydrogen. The pure gas has very little odour, the garlic like smell of generated acetylene being due to its impurities. Unlike some other gases, it has no action upon metals when pure, but its impurities cause it to re-act in somewhat peculiar manner with copper, which forms the explosive compound known as copper acetylide. It is non-poisonous when pure and in small quantities, but suffocation will take place when 40 per cent of the gas is in the atmosphere.

It also has some antiseptic properties. It condenses into a liquid at about 1° C., and 720 lbs. to the square inch pressure, the liquid solidifying when cooled to a lower temperature. When mixed with oxygen it explodes more violently than any other of the hydro-carbon gases.

It forms a long range of explosive mixtures with air, any percentage between 3 and 80 becoming explosive on ignition. It also has the property of what is known as polymerization, which means that it splits up into other compounds when heated in a closed vessel, one compound which is formed at a red heat being benzine. In a glass container it will also decompose in sunlight. It is slightly soluble in water and turpentine, each of these liquids dissolving a volume equal to its own.

Of all liquids the hydro-carbon acetone has the greatest dissolving power, one volume of this liquid dissolving about 25 volumes of acetylene. The impurities found in generated acetylene are—

(1) Phosphorated hydrogen, which is obtained from the decomposition of calcium phosphide in the carbide by water and in burning with the acetylene, gives rise to what is known as phosphorus pentoxide, which can usually be detected where impure acetylene is burnt by a light cloudy appearance in the atmosphere.

(2) Sulphuretted hydrogen, which is formed by the action of water on the aluminium sulphide, etc., and yielding when burnt sulphur dioxide, which if dissolved by any mixture in the atmosphere will absorb oxygen and form traces of sulphuric acid.

(3) Ammonia from the nitrides in the carbide. This is the active gas which rapidly corrodes brass fittings, and on burning produces small quantities of nitrogen acids.

Several processes have been devised for the purification of acetylene by the removal of the above compounds. The only impurity that offers any real difficulty in removal is the phosphorated hydrogen, and three substances have

been suggested and used in practice for this purpose, namely—

(1) Bleaching powder.

(2) Acid copper or iron salts.

(3) An acid solution of chromium acid.

When bleaching powder is used it should be in the form of small lumps so as to offer the least resistance to the flow of the gas.

Acid solutions of copper chloride are also effective in removing the various impurities, but seeing that copper may form the dangerous explosive already mentioned, it is doubtful whether it is wise to use such a solution as this.

Chromic acid in solution containing either acetic or sulphuric acid is sometimes used as a purifying agent, and has the power of eliminating both the phosphorus, sulphur, and ammonia. In later years, however, there has been no need to fix up chemicals as above for purifying purposes, as several compounds, such as catalysol, puritol, etc., have been put upon the market and these, when used in a proper manner, give the necessary purifying effect for all that is needed in the way of acetylene to be used for welding purposes.

Carbide of Calcium. As acetylene is now always generated from carbide of calcium some consideration should be given to this latter compound.

Calcium carbide is composed of 62·5 per cent of the metal calcium combined with 37·5 per cent of carbon.

Whilst calcium carbide was produced in small quantities more than half a century ago, it was not until about 1892 that it was produced on a commercial scale. This was very largely brought about by the introduction of the electric furnace worked by cheap water power. In the electric furnace it is prepared by the inter-action of lime and carbon, the latter taking the form of ether coke or anthracite.

The temperature of re-action in the making of calcium carbide varies from 2,000° to 3,000° C., and the re-action which takes place is represented by the following—

Lime		Carbon	Calcium Carbide		Carbon Monoxide
CaO	+	$3C$	CaC_2	+	CO

During the process the lime is liquefied, whereupon the carbon enters into solution, and also carbon monoxide gas is evolved.

If the materials that are used in the making of carbide contain much phosphorus it is a disadvantage to the generated acteylene, as this forms phosphorated hydrogen which produces noxious fumes when the gas is used, and also renders the acetylene liable to spontaneous ignition. The presence of aluminium and iron also reduces the quality of the carbide, rendering it dark in colour. Impurities seriously affect not only the rate at which the acetylene can be generated, but also the quantity and the quality of the gas produced. Examination under the microscope of polished sections of carbide of calcium show that it has a granular structure (*see* Figs. 125 and 126), this varying very considerably with the quality of the carbide. In impure carbide two or more different kinds of micro structure can be observed in the material.

It is rather interesting to note that powdered calcium carbide can be used as a deoxidizing flux when mixed with borax for both copper and copper alloys.

The chemical re-action which takes place when water is brought into contact with carbide is shown by the following formula—

$$\frac{CaC_2}{\text{Calcium carbide}} + \frac{2H_2O}{\text{Water}} = \frac{C_2H_2}{\text{Acetylene}} + \frac{CaOH_2O}{\text{Lime}}.$$

It will be seen that the carbon of the calcium carbide combines with the hydrogen of the water to form acetylene, the metal calcium of the carbide combining with the oxygen of the water to form lime.

Careful manipulation of a job is imperative during the process of welding. In repairing a crack the welding should not be done to the full extent on one side or a crack is sure to result on travelling back to complete the opposite side. The watching of points such as this will save a good deal of subsequent trouble.

Aluminium Alloy. Aluminium alloy should be pre-heated to 400° to 450° C., care being taken that a higher temperature is not attained, as castings will collapse with their own weight at about 550° C., the melting point being a little higher than this. As there is no change in the colour of the metal up to the temperatures indicated the greatest care must be taken in the pre-heating of articles for fear of collapse. Some expert welders watch for the aluminium casting to what they call sweat, which means that one of the low melting constituents of the casting commences to melt. This method can be followed if the greatest care is exercised and the surface of the alloy continually tried by scratching, the first indications of any softening plainly showing that the metal has been heated sufficiently high. Until such times as the welder becomes expert support should be made for all work that is likely to give trouble, and for this purpose plaster of Paris can be mixed to a paste and shaped to form the mould, allowing same to be baked solid. Before this is fixed into position a layer of wet paper or asbestos sheet should be placed on the under side of weld in plaster mould.

The application of this method will enable the welder of small experience to carry out jobs until he gains sufficient confidence to perform them without the aid of supports.

An aluminium casting of double shell if cracked on the outer surface is likely to give the welder of little experience some trouble. For the successful welding of a job of this kind it is imperative that the inside should be pre-heated as well as the outer shell, so as to allow it to expand at the same rate as the outer skin. This can be accomplished

by having a blow-lamp blowing judiciously on the inside whilst the outside is being welded. Unless some such method as this is followed it will be difficult to carry out the job properly.

At this stage it will, perhaps, not be out of place to briefly go through the welding of a broken top water pipe for a motor car cylinder, Fig. 39. This is rather an awkward job to pre-heat, and is easily warped unless contraction

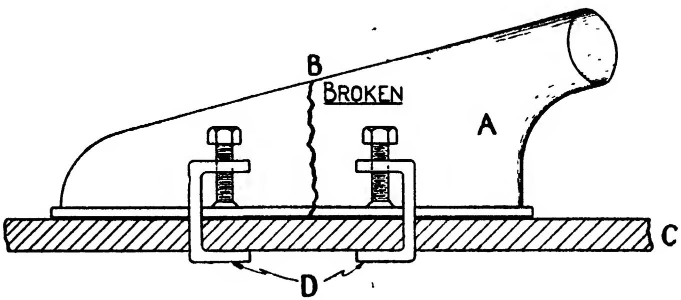


FIG. 39.—ALUMINIUM WATER PIPE

A = Aluminium casting (2 pieces) fitted together.
B = Shows break and starting point for welding.
C = Machined *C.I.* plate.
D = 2 Clamps.

is guarded against. A useful method to follow is to first of all prepare the casting and then attach it to a machined plate with clamps, as illustrated. The whole zone to be welded should be kept at an even temperature. The welding should be carried out by first of all commencing at the centre and travelling towards the edges. It is not advisable to commence at the edge and travel over to the opposite side as it is pretty certain that a crack would follow the operation as soon as the line was completed, but by starting at the top and working from that point to each side will tend to equalize the contraction stresses in cooling.

Some guidance with regard to overcoming troubles set up by expansion and contraction can be obtained from the following summary, but it should always be remembered that the actual carrying out of work after due consideration of all the conditions will be the best teacher that a welder can have.

The advice given can be summarized under four headings as follows—

(1) To bring the work to be welded, and particularly the joint portion, to a definite temperature according to the kind of metal under repair.

(2) To heat certain portions of the work so that the contraction of these parts will take place at the same time and at the same heat as the welded area.

(3) The cutting or breaking of rigid members before welding at the rigid zone, and afterwards welding the members which have been so broken.

(4) To localize the heat and thus the effect of expansion and contraction by submerging a portion of the work in cold water. Or by wrapping around parts of the job with asbestos and pouring water on same during the welding operation or until the repair is completed.

If the welder will do some thinking on the lines of the above hints he will find that after some experience he will be able to carry out work which is thought by some to be impossible. It should be remembered that with every change of temperature a metal alters its length, breadth, and thickness, and to overcome these changes by the application of any external force is practically impossible. Hence, the welder must learn to apply all kinds of dodges to overcome this inherent difficulty in welding, if his resulting work is not to suffer through distortion, fractures, or other defects.

Repairing Aluminium-Alloy Case. As an illustration of a repair that can be carried out successfully by the application of hint No. 3, the alloy case shown in Fig. 40 is an

example. The case had been broken at *A*, and if this had been welded without taking thought as to the subsequent result it is pretty certain that a crack would have appeared after welding. The method followed, however, was to cut through at the point *C* between the two rigid members. At the point *B* the metal would be heated up to a high temperature on account of the rapid conduction of heat to this point. There would, therefore, be a large amount of expansion, and on cooling a corresponding amount of contraction. After cutting as indicated, the broken part at *A* is first welded, the case is then pre-heated to about 450° C. along the dotted line shown, and finally welded at the joint *C*, when it will be found that the subsequent contraction will bring the case back to its normal shape and size.

Repairing Broken Aluminium Crank Case. The crank case was fractured at the point *ABCD* (Fig. 41). The method of procedure is as follows—

Procure a shaft of such a size to suit the bearing and having placed the broken portions in position set the shaft in the four bearings with the two outside ends packed up $\frac{1}{64}$ in. This, of course, can be easily done by inserting a piece of metal of the required thickness. Draw up the centre bearing to the shaft with the caps or secure with wire passed through the bolt holes. This arrangement will allow the broken bearings to sink down $\frac{1}{64}$ in. on contraction, thus bringing them in alignment with the two outside bearings.

Then tack at the points *ABCD* securely, afterwards removing the shaft and packing. Now gently pre-heat the whole of the case and carry out the welding. Slow cooling is essential as it is very important that any form of sudden cooling or draughts should be avoided.

Cast Iron Repairs. A very common job to be done is that of the repairing of broken cylinder lugs. An experienced welder can easily carry out this repair without

pre-heating the whole of the cylinder, the method followed being to weld the lug and cylinder wall, taking the necessary precautions to fix the lug sufficiently higher than the other three lugs so that when the welding is

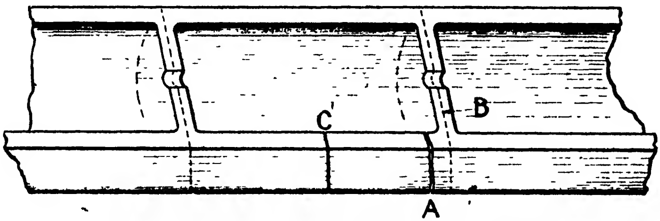


FIG. 40.—ALUMINIUM CASE METHOD OF PROCEDURE

A = Break.
B = Conductivity of heat very great.
C = Cut through with saw to overcome the effects of *B*.
(1) Weld *A* first.
(2) Pre-heat at dotted lines to 450°C. and weld *C* last.

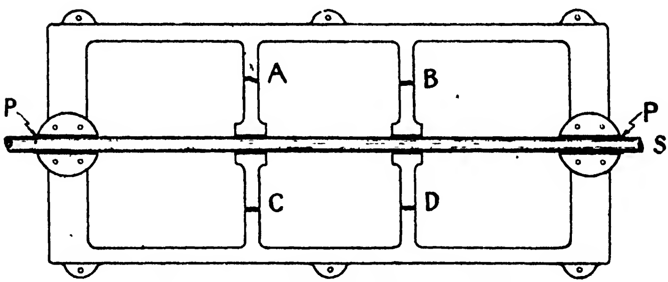


FIG. 41.—ALUMINIUM ALLOY CASE

A, *B*, *C* and *D* = Broken portions.
S = Shaft.
P = Two points to pack $\frac{1}{64}$".

finished and contraction takes place it will come to the same level as the remainder.

It is perhaps as well to again remind the operator that when a blow-pipe flame plays upon metal the tendency of the joint on cooling is to form a *U*, as shown in Fig.

42 (*a*) and (*b*). If the joint, however, is raised up before welding as shown in Fig. 42 (*c*), it will then have a tendency to draw straight in cooling.

A good practical method sometimes adopted for welding broken lugs is to do all the bevelling from the inside, and when setting up to insert a piece of broken hack-saw blade

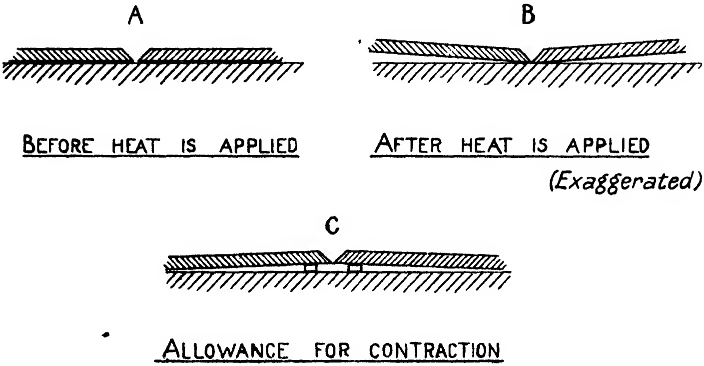


FIG. 42

under each edge of the cylinder nearest the broken lug. Then place the lug in position with the bevelled edge resting on the saw blade. Draw down at the bolt hole with clamp attached to a machined surface plate, thus causing the edge to be the thickness of the saw blade lower at this point than the three unbroken lugs. This arrangement it will be found will just about give the right allowance to cover for contracting. After setting up as above a cylinder must be heated in all four lugs, otherwise the bore will be badly distorted or warped, as shown in Fig. 43.

In welding the four lugs are first heated, the broken lug then being tacked into position. After tacking the clamp removed, the welding is then being carried out. To ensure

slow cooling it is a good plan to place the finished job near to a fire, at the same time taking care that no air draughts come in contact with the cylinder.

In doing welding repairs on a block of cylinders the greatest care must be taken with regard to pre-heating and contraction, so that parts away from the actual weld are not distorted.

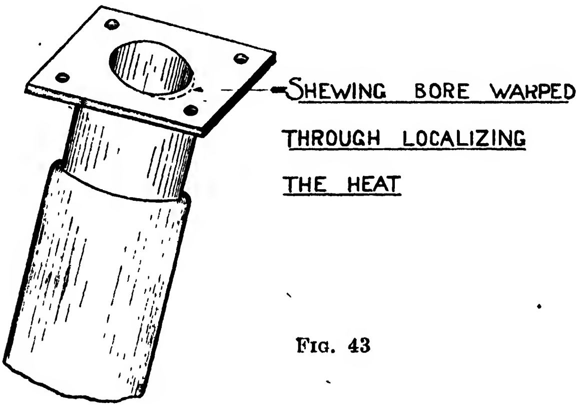


FIG. 43

Repairing Cast Iron Wheel. Let us suppose that the three arms of a wheel or pulley are broken as shown at *ABC* in Fig. 44, No. 1. If the three arms are welded up without pre-heating it is pretty certain that one or more will break through contraction on cooling, or immediately the wheel is brought into service. If the whole wheel can be brought up to a high temperature by pre-heating and welding of the arms carried out step by step, that is allowing the temperature of the joint to fall down to that of the rest of the wheel before commencing the second arm, then it is possible a good job may be effected. But a method that could be carried out with success is to cut the rigid member at *D*, then, after preparing the Vees,

weld in the following order—C, then A, then B. Finally, the arm portion $F H K$ should be carefully pre-heated and the weld made at the joint D. If slow cooling then takes place a satisfactory job will result. If the work has to be carried out without cutting the rim it will be a great advantage to keep the boss at a lower temperature than either the arms or the rim, as this will tend to balance the contraction strain set up through the welding of the last arm.

Welding Cast Iron Frame. Supposing the frame (Fig. 44, No. 2) is broken at the parts 1, 2, and 3, the method to be followed to obtain a successful job would be to weld 1, then 2, then carefully pre-heat the second about the part No. 4, this being kept at a good heat whilst the welding proceeds at No. 3. Some little practice and judgment in connection with the pre-heating will show just the requisite amount to balance the contraction strains at No. 3 by those that will be set up by the cooling at No. 4.

Repairing Broken Cast Iron Bracket. A cast iron bracket of Tee section is broken at three parts as shown in Fig. 44, No. 3. The repair can be carried out by first welding No. 1, then No. 2, then pre-heating about the joint No. 1 and welding at No. 3. Or if No. 2 is to be the last weld it will be an advantage to pre-heat at No. 3 and also at the part marked No. 4.

Repairing Cast Iron Box Pattern. Sometimes the repair of a cast iron article can be carried out in the cold state by using mechanical means to balance the force of expansion and contraction. An operator of some experience will readily understand the following—

If a box is fractured along the corner marked A (Fig. 24), by carefully forcing a wedge into the crack the fracture can be opened a little further, and in this way an opposite stress will be set up, which, after cooling will balance the contraction and so enable the box to be repaired without danger of further fractures. No pre-heating is required.

After forcing in the wedge the welding should commence and when nearing the end of the joint the wedge can be

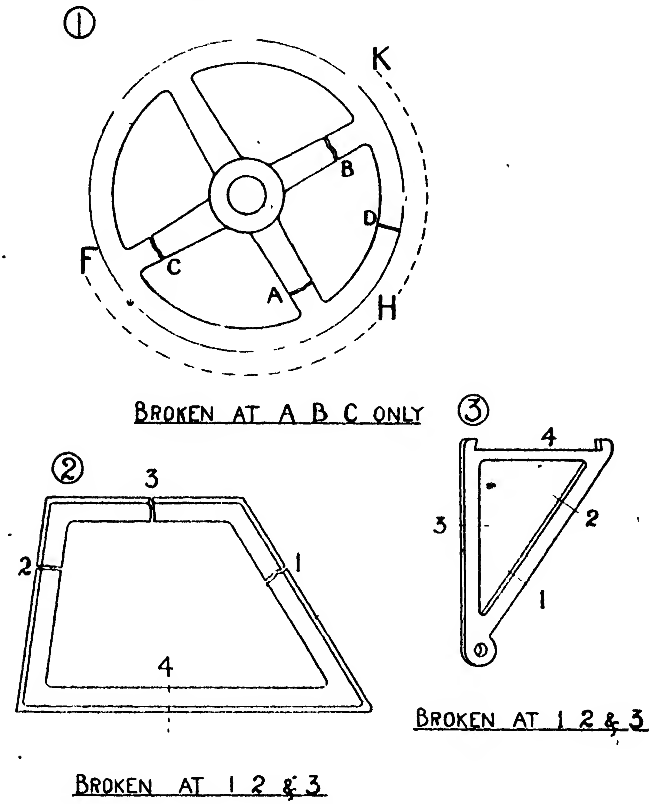


FIG. 44

knocked away and the weld quickly completed. If some such method as indicated above is not adopted it would mean that the box would have to be pre-heated at the corner *C*, or a rupture at that point would be pretty certain to take place.

Repairing Cracked Water Jacket. If the welder has to operate on parts where the metal has varying thicknesses the first essential requirement is the slow heating of the casting, a pre-heating oven being the ideal arrangement for carrying out this operation. If this is not available an improvised fire may be built of fire bars and fire bricks. If the heating is carried out on a smith's forge the fire should not be used whilst the casting is in the fire, and if gas is used as a heating fuel the ordinary yellow flame should be adopted by cutting down the air supply or eliminating the forced draught.

The cylinder after being prepared for welding should be placed head downwards in the fire and the pre-heating continued until the job is brought up to a dull red heat. Re-heating after welding is also advisable, as this tends to equalize any undue strains set up by the high welding heat on the structure near the welded job. Slow cooling should always be carried out so as to eliminate as far as possible any internal strains which might result in a fracture when cooling down. Also, as it is absolutely necessary that the slow cooling should be uniform all over the job, the latter should be protected from all atmospheric draughts.

Another extremely useful point is to protect the bore of cylinders, valve seats, and any other machined surface that is likely to scale during the pre-heating and welding: This can be done by making a paste of graphite and oil with which the surfaces can be coated.

Repairing Cylinder Compression Head. A portion of the outer jacket should be first taken away, Fig. 45, so as to allow the head to be got at with a blow-pipe, then all rust should be mechanically removed.

The bevelling or cutting of the Vee for the joint should be carried not quite to the bottom of the crack, so as to avoid rough spots or globules of metal protruding through into the compression space.

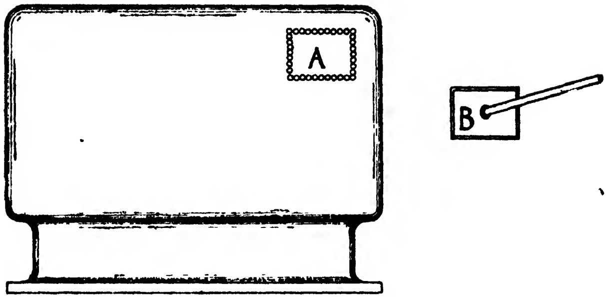


Fig. 45.—Removing Portion of Cylinder to get at the Compression Head

A — The piece which is drilled out.
B — The piece ready to go back with the rod tacked to it for fixing in position

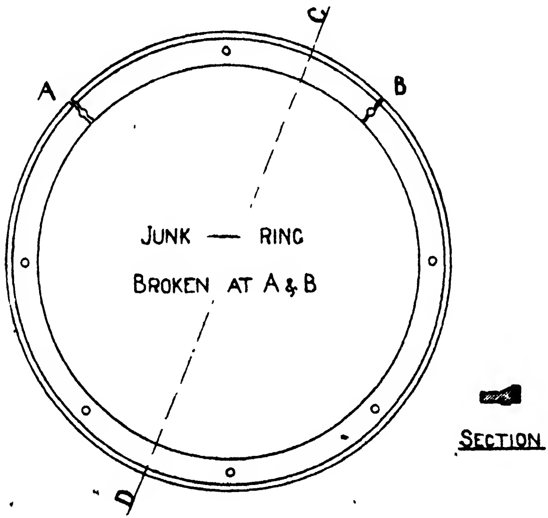


Fig. 46.—Illustrations showing where Clamp can be Conveniently Applied

(1) Weld *A* over a fire and when finished the adjustable clamp can be applied at *C* and *D* to bring ring to its original shape.
(2) Re-heat over fire and allow to cool slowly for 24 hrs. This will overcome contraction and make the metal workable for machines.

If the fracture runs close to the valve chambers it is advisable first to weld the metal adjoining the heaviest section, leaving the part of the weld which runs into the even thicknesses until the last.

When replacing the piece that was originally cut away from the outer shell, it is a good plan to tack the welding

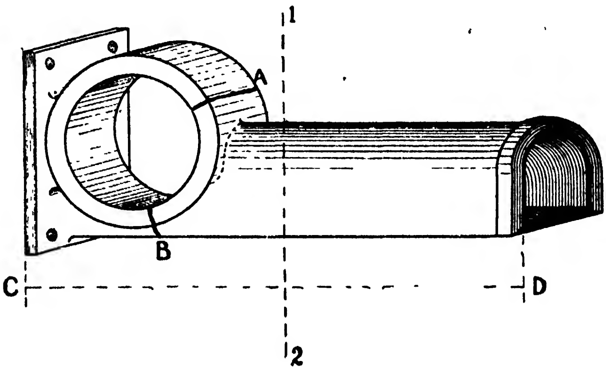


FIG. 47.—CASTING DISTORTED THROUGH FRACTURE

Broken at *A–B* and out of shape.
Prepare and weld section *A* first.
Re-heat across 1–2 and clamp across *C*–2 to pull into original position, then secure by welding.

rod to this piece which will enable the operator to have some means of fastening it into the exact position.

The repairing of a junk ring is shown in Fig. 46, this bringing in the use of clamp previously mentioned.

Castings are often distorted due to fracturing, and considerable care must be exercised to bring them back to their correct shape. An illustration of this class of work is shown in Fig. 47.

Having read through the instructions and hints that have already been given and actually carried out some work in practice, the welder by this time should be able

to follow and understand the main principles that are essential for successful welding.

Generally, it is a good method to spend some little time considering the work to be done and the best means and methods to be adopted, picturing at the same time what is likely to happen as the welding proceeds. In this way the practised welder will soon readily find out ways and means of overcoming any defects that may crop up in carrying out the job, and also any after defects that might result from thoughtless operations.

In connection with many cast iron repairs " More haste, less speed " might with advantage be taken as a useful motto.

Finally, it might be mentioned that it will be an advantage to read and study the chapter which deals with " Don'ts."

CHAPTER XV

THE TESTING OF WELDS

THE testing of welded joints on a finished piece of work is not by any means a simple matter. If the joint is on a vessel which can be totally closed, tests can be made by water pressure, and in this way the strength of the weld determined with regard to standing some maximum pressure. But even for pressure purposes this alone is not sufficient, as a joint may be sufficiently strong to withstand the tensile stress engendered by internal pressure, and yet at the same time so hard as to fracture if it received a slight shock. The most that can be said for a water pressure test is that it will prove whether or not the joint is sufficiently well made to stop any form of "weeping." But even if the pressure is applied with a water test this will not be sufficient to ensure that the joint will be perfectly tight against petroleum, petrol, or other what might be called "thin" liquid.

Some investigations have taken place in connection with the use of X-Rays on welded joints, but whilst these will show up voids and inclusions, this method of testing does not convey much idea of the real quality of a welded joint. For the highest class of work there can be no better plan than for a welder first of all to make sample joints in the same quality of material which he is called upon to use, and to subject these sample joints to all kinds of tests, such as tensile, elongation, bending (Fig. 48), and microscopic. Then, if he can uniformly produce high class welds in this way it is a fairly good indication as to the quality of work that he will produce in connection with some article of construction.

Perhaps for mild steel plate water tanks which have not

to be subjected to a very great pressure, a simple method of testing is to well paint one side of the joint with a solution of paraffin and red lead, which if the joint is porous will

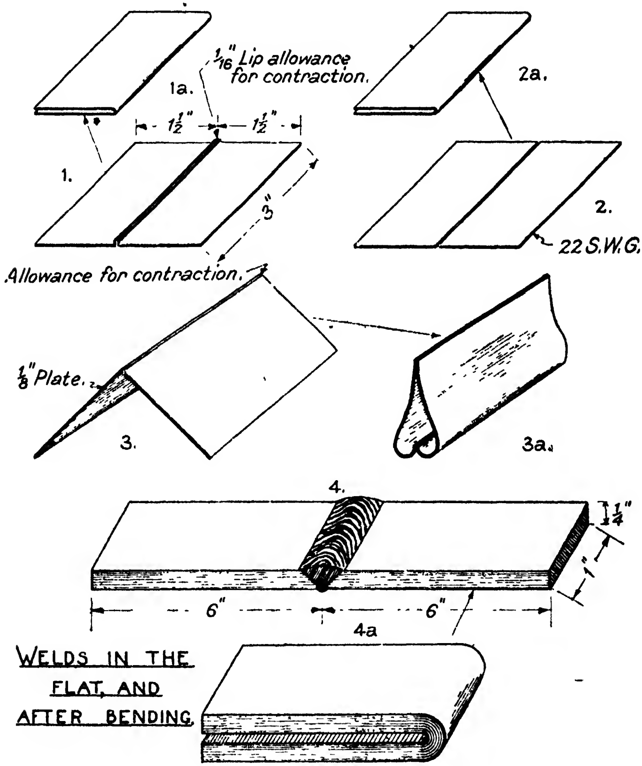


Fig. 48

show on the opposite side through a gradual "creeping" of the solution.

A filled in Vee weld, it should not be forgotten, is nothing more or less than a mould into which fused metal has been run after the sides of the Vee have been melted down.

The run in metal if left in its natural condition will, of course, be the same as one would expect from material in the cast state. If the same properties as obtain with the rolled plate have to be engendered into the weld it is necessary that it should be subjected to some such treatment as the plate material has received, which means that work must be done upon the steel in the hot state. So that wherever possible it is always advisable if a strong joint is required to not only see that the weld metal is properly fused into the joint, but that it is carefully hammered at the correct temperature. In this way the large grain of the cast material will be broken down or refined, the resulting weld left in a much better condition not only to resist shock, but to give maximum elongation.

It is often a problem as to how best to get the greatest tensile strength of a weld, together with a degree of elongation which is nearly equal to that of the material to be welded, and to obtain this is no easy matter, as it requires a good deal of thought right through the process of joint preparation, welding and after-treatment. It should also be remembered that however carefully the welding is carried out it is practically impossible to ensure that the resulting filling-in material of the weld will be of the same chemical composition as the plate material. If this condition can be obtained it will always be an advantage from the point of view of high quality of weld and the reduction of any tendency to corrosion through dissimilar materials being joined together.

As will be seen from particulars given in this chapter, there is generally a big loss both of carbon and manganese in the steel as it passes from the condition of the filling wire through the flame or electric arc to form the weld. The use of a flux both in acetylene and arc welding will assist to keep the constituent elements in the steel as it passes through the fusing process, and also careful manipulation of welding will help to serve the same purpose. Thus, in

acetylene welding, the longer the metal is kept in a molten state generally the greater will be its change in chemical composition, and in connection with arc welding usually the maximum change in the composition of the steel takes place when a long arc is used.

A careful perusal of what follows in this chapter will enable the welder to appreciate what happens with various metals under different welding conditions.

Whilst to the casual on-looker the carrying out of any form of fusion welding seems to be a very simple process, to those who have had experience and know, it is not an easy matter to make any form of welded joint to give the best possible result. Good welders, indeed, are sometimes puzzled with the kind of results they obtain, simply because some factor which is outside their control may creep in and entirely upset their calculations. There are so many things which affect the making of a good welded joint, that it is not surprising that results are so variable. It is, therefore, essential that careful scientific investigation should be regularly carried on so as to put operators in the way of guarding against all possible defects in their work. Apart from physical deformation the most common form of defects found in nearly all kinds of welds are—low tensile strength and poor elongation. These mechanical defects result either in brittleness or indifferent bending qualities of the joint, and offer small resistance to fracture by shock. Low elongation is certainly one of the defects that can be seen when joints are being tested for tensile strength in the testing machine, as the amount of plastic stretch at the joint portion of the plate is usually very small.

Whilst speaking of the defects in welded joints it should not for a single moment be thought that any of the various systems of welding in vogue are generally in default, for all of them in one way or another do very good work. A comparison of the different methods of welding is very

difficult to make either to the advantage or disadvantage of any particular system. One thing, however, is quite certain, that each system under certain conditions has its own useful sphere of operation.

Referring again to the previously mentioned mechanical defects it may be said that whilst these are well known, the cause and cure of same are not so easy to fathom, and it is in this direction that it is necessary to make very careful investigation. One of the best ways by which information can be obtained relating to welded joints is to have a large number of experimental welds made by ordinary methods of working and to subject these to what may be called a process of anatomizing by the use of the microscope supplemented by chemical analysis and physical tests. This method has been adopted by the author for some years in connection with all kinds of welding processes, and much information has been obtained which explains the cause of defective welds.

Micro-Structure of Iron and Steel. Before showing any of the defects which are set up in joints, it will, perhaps, be as well briefly to explain the kind of micro-structure found in wrought iron, mild steel, etc., from which it will then be possible to make a comparison with a welded joint structure of the same material. It should be particularly remembered that the structure of a metal and its physical properties not only depends upon its chemical composition, but also upon the kind of heat treatment it receives and the amount of work that has been done upon it either in rolling or hammering, and that the particular structure engendered through this treatment is often entirely upset when the metal passes through any form of fusion welding. Hence, this explains how difficult it is to make a welded joint in which the filled-in material should not only have the same chemical composition as the plate welded, but also have the same physical properties.

The micro-structure of a piece of wrought iron is shown

Fig. 49.—Wrought Iron, Unetched

Fig. 50.—Wrought Iron, Etched

in Fig. 49. To obtain this the surface of the iron has been highly polished and the photograph taken to a magnification of 100 diameters. (Before passing on it will be as well to remember that the following micro-photographs, except where otherwise stated, are all to a magnification of 100 diameters.)

The grey bands seen in Fig. 49 are the well-known slag threads that are always found in wrought iron. Fig. 50

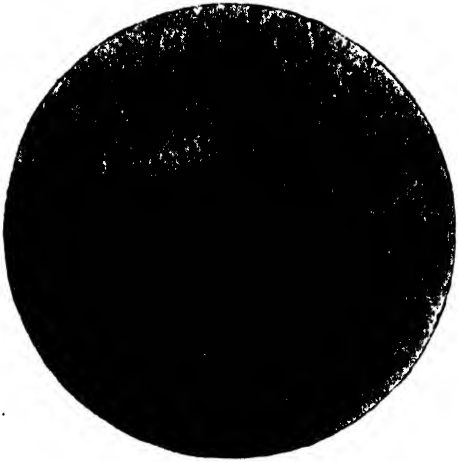


FIG. 51.—ACETYLENE WELD IN COMMON IRON BAR

shows the structure of a piece of wrought iron after it has been polished and etched with dilute picric acid. The etching, it will be noticed, has not only brought up the grain structure of the wrought iron, but also shows that the slag has a compound structure. The junction of a good acetylene weld made in wrought iron is shown in Fig. 51, in which it will be seen that there has been complete fusion, the most noticeable feature being that the slag threads have been balled up into small globules in passing through the welding state. The structure of a mild steel is shown in Fig. 52. Upon examination of this it will be noticed

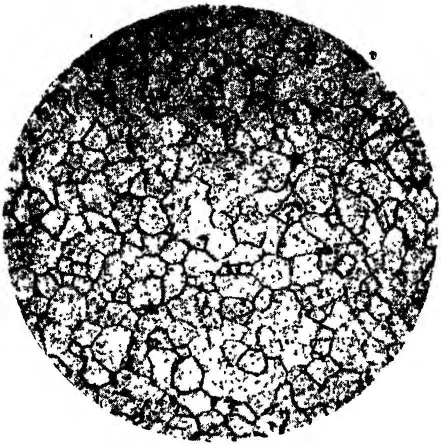


FIG. 52.—MILD STEEL

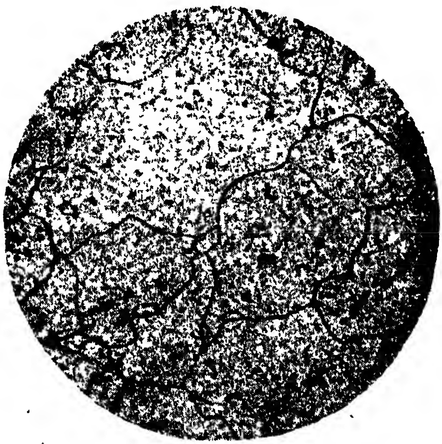


FIG. 53.—MILD STEEL, OVERHEATED

that in between some of the grain boundaries there are small dark areas, this being what is known as the pearlitic structure and containing the carbon. Fig. 53 is of identically the same steel, which has been somewhat overheated causing enormous grain growth resulting in the material being brittle and showing a coarse crystalline fracture.

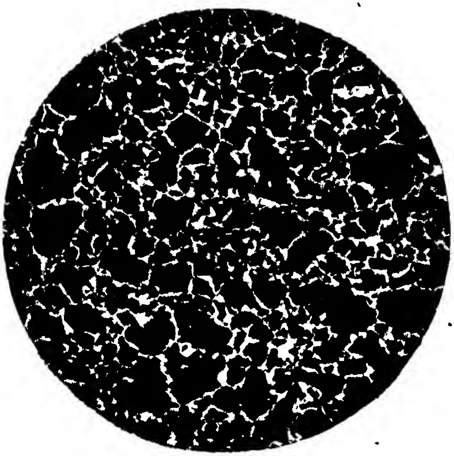


FIG. 54.—STEEL, ·55 PER CENT CARBON

The structure shown in Fig. 54 is of ·55 per cent carbon steel, and in this it will be noticed that the black areas of pearlite have considerably increased, the white areas of iron, or ferrite as it is called, now being reduced to a network structure.

It will be interesting to observe that the pearlite has a distinct structure of its own, this being shown to the higher magnification of 1,000 diameters in Fig. 55. It will be seen that the structure is of a laminated character, the alternate layers being respectively composed of carbide of iron and ferrite.

The amount of carbon in pearlite is always ·89 per cent and this is a fact which should be borne in mind in the

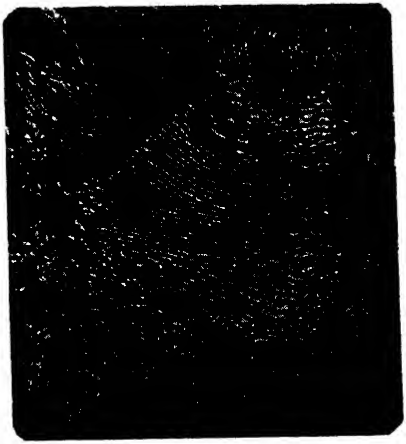


FIG. 55.—PEARLITE STRUCTURE IN STEEL. MAGNIFICATION, 1,000 DIA.

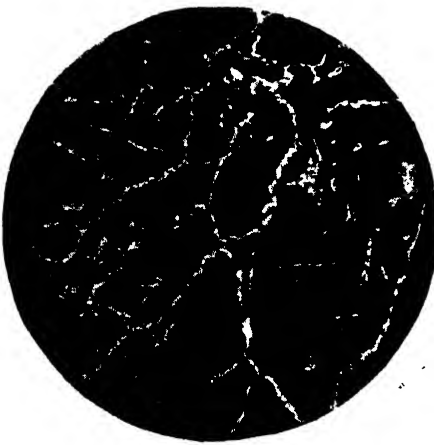


FIG. 56.—ANNEALED STEEL, 1·4 PER CENT CARBON

examination of the structures of the different steels, as when in the normal or annealed condition the kind of structure will indicate the carbon point of the steel.

To exhibit the structural formation of a steel that contains more than ·89 per cent of carbon, the micro-photograph Fig. 56 has been prepared, the dark areas in

FIG. 57.—QUICKLY COOLED STEEL, 1·4 PER CENT CARBON

this showing the pearlitic formation, and the white network in this case being of the hard carbide of iron. This steel when quickly cooled gives a structure which is entirely different and this is shown in Fig. 57, in which the hard brittle structure of martensite is seen. This is the characteristic structure which is often engendered in very quickly cooled welds of high carbon, which will inevitably result in fracture if not properly annealed.

It ought to be well known that the resulting structure of a steel and its corresponding physical properties will depend in a large measure upon the amount of work that is done upon the steel in the hot state. Thus in Fig.

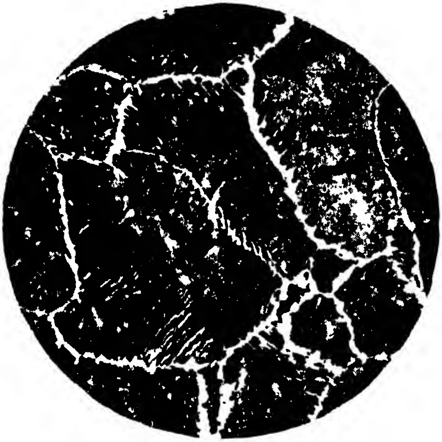


FIG. 58.—·50 PER CENT CARBON STEEL AS CAST

FIG. 59.—·50 PER CENT CARBON STEEL, FORGED

58, a micro-photograph of a ·50 per cent carbon steel is shown just as cast into a small ingot. In this photograph it will be seen that the grains are very large, there being only three or four covering the surface photographed. The structure of the same steel after being carefully

FIG. 60.—FIRE WELD IN MILD STEEL AND WROUGHT IRON

forged down and finished at a dull red is shown in Fig. 59. In this it will be noticed that the grain growth has been such that the area marked out by one of the large grains in Fig. 58 is now covered by about 100 grains in Fig. 59, with the result that this material is considerably tougher than when in the cast state, although its chemical composition is exactly the same.

Micro-Structure of Welds. As we are dealing with all kinds of welds, it will not be out of place to bring in the old-fashioned blacksmith's fire weld, and to illustrate this the micro-photographs, Figs. 60 and 61, have been prepared. Fig. 60 shows the junction of wrought iron welded to mild steel, whilst Fig. 61 shows the junction in the weld.

FIG. 61.—FIRE WELD IN MILD STEEL AND MEDIUM CARBON STEEL

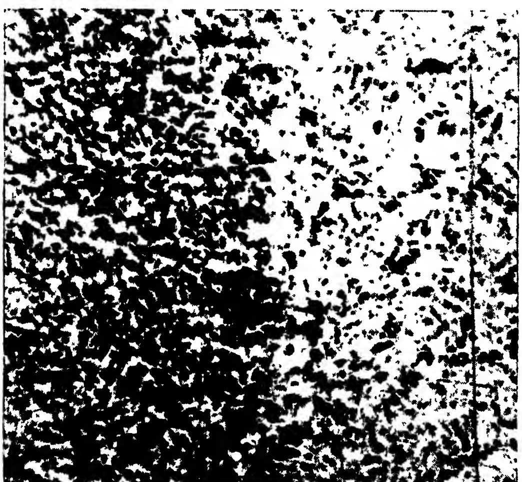


FIG. 62.—ELECTRIC ARC WELD

mild steel and medium carbon steel. In both of these welds it will be observed that there is complete fusion, the result being, on testing, that each of them gave 100 per cent efficiency. Fire welding, like, indeed, almost any other form of welding, depends very largely upon the quality of the blacksmith, and whilst it has been said that a fire weld gives a strength of 80 per cent of the solid bar,

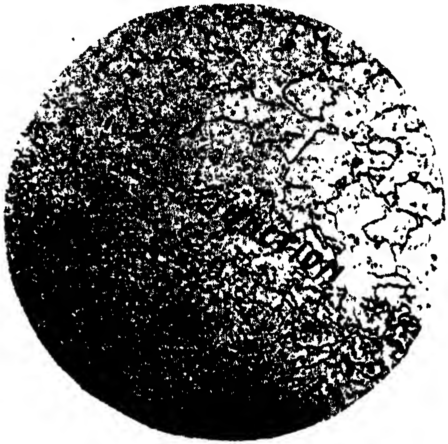


FIG. 63.—GOOD ACETYLENE WELD IN WROUGHT IRON

it is never safe to fix any percentage without intimate knowledge of the character of the particular blacksmith's work.

The junction of metals in a good electric arc weld is shown in Fig. 62, in which it will be observed there is complete fusion of the joint; this is also seen in the good acetylene weld in wrought iron in Fig. 63. The last two again giving an efficiency of 100 per cent. Fig. 64 is of a good acetylene weld in mild steel which shows complete fusion at the junction, but rather large grain on account of not being hammered.

FIG. 64.—UNHAMMERED ACETYLENE WELD IN MILD STEEL

FIG. 65.—SLAG IN ACETYLENE WELD

Weld Defects. Now we come along to deal with some of the defects that are found in welds which are the cause of their very low efficiency, either from the point of view of strength or toughness.

The micro-photograph, Fig. 65, is of an acetylene wrought iron weld showing a layer of slag in between

FIG. 66.—FRACTURED ACETYLENE WELD

the weld and the bar, due to the surface of the bar not being properly fused before the filling material has been run in. A weld such as this, of course, simply falls apart under a slight pull or bend. This is shown in Fig. 66, where it will be observed that the actual fracture has taken place along the line of slag. Perhaps a better illustration of imperfect penetration in an acetylene weld is shown in Fig. 67, this being of a thick bar formed of a double Vee. The bottom Vee was filled in fairly solid, but it will be seen that the root of the top Vee is unjoined, the filling having been run in without being fused to the bar.

FIG. 67.—IMPERFECT PENETRATION IN ACETYLENE WELD

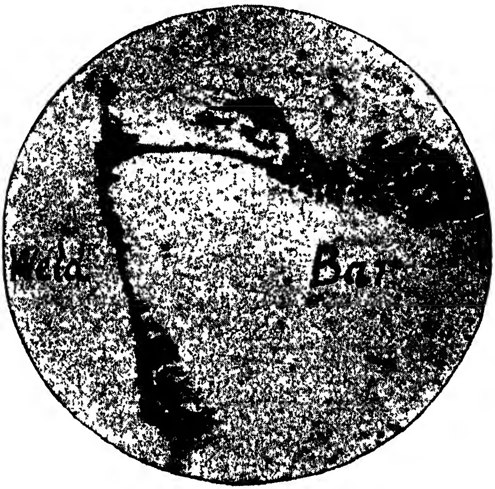


FIG. 68.—SLAG IN BAR AND WELD

Sometimes in the welding of very common wrought iron, without the greatest care, the slag thread in the bar may be melted and run down at the junction of the bar and filling. This is shown in Fig. 68, where it will be noticed that the slag thread has practically been turned over at right angles along the junction. In arc welding,

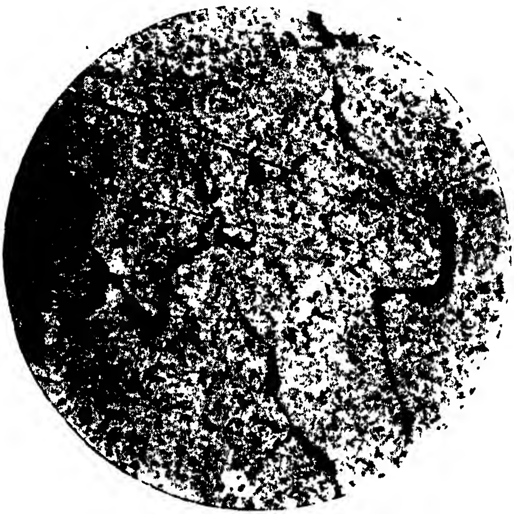


FIG. 69.—SLAG THREADS IN ARC WELD

also, without great attention, slag may be included in the filling material. This is illustrated in Fig. 69, where slag ribbons are shown in the weld. In Fig. 70 a blob of slag in an arc weld is exhibited ; this, it will be observed, having a distinct structure of its own. Included slag in a weld will inevitably result in a weakening of the joint.

Using an oxidizing flame or prolonged playing upon the molten metal with a blow-pipe flame, will result in the filling material of an oxy-acetylene weld being charged

FIG 70.—SLAG IN ARC WELD

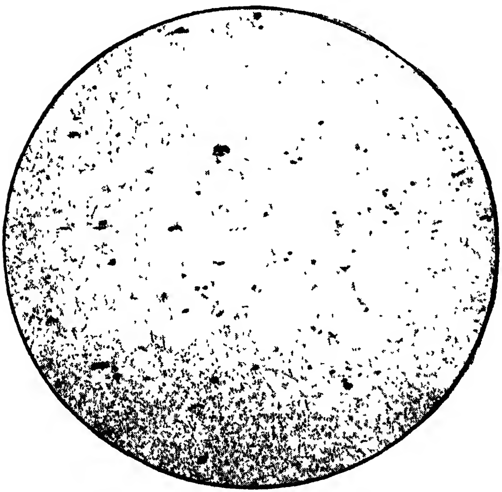


FIG. 71.—OXIDE IN ACETYLENE WELD

with oxide specks. These are seen in great numbers in Fig. 71, the metal being simply polished and photographed without etching. Welds of this description are bound to be of a brittle character. In addition to oxidizing the weld, large grain growth is often engendered by prolonged heating, and this defect is shown in Fig. 72. If not badly

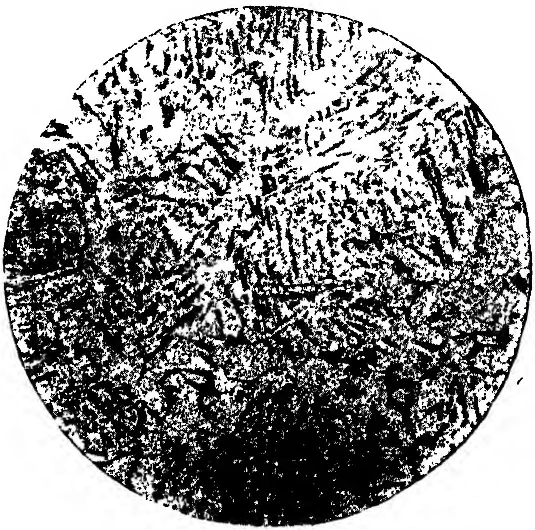


FIG. 72.—OVERHEATING IN ACETYLENE WELD. MILD STEEL

oxidized, a weld like this can be considerably improved by hammering. In connection with this the term "overheating" should not be confused with that of "burning," although in practice it is very usual to use both terms to cover the same phenomenon. When the metal is burned, hammering will not bring it back to its normal condition, and nothing short of actually remelting the metal and purifying it will restore its full properties. An illustration of the actual burning of a metal is shown in Fig. 73, which

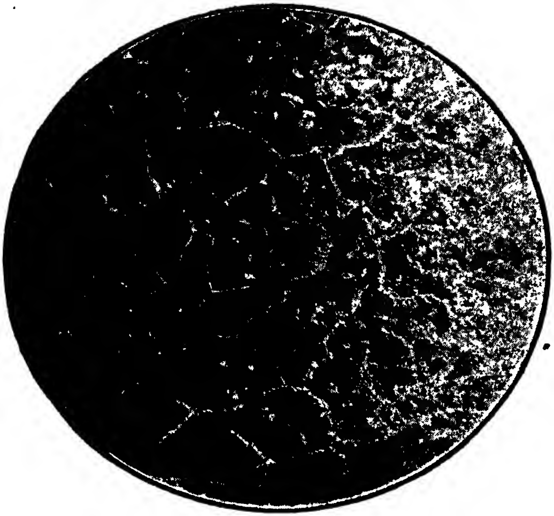


FIG. 73.—BURNING IN ACETYLENE WELD

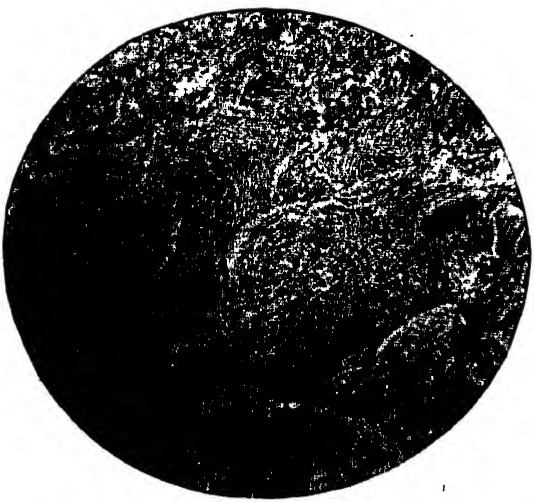


FIG. 74.—OVERHEATING IN ACETYLENE WELD. MEDIUM CARBON STEEL

is of a weld in medium carbon steel, and if the same photograph is compared with that of Fig. 74, which is an acetylene weld of the same material that has been overheated, it will be seen what a distinct difference there is in the resulting structure.

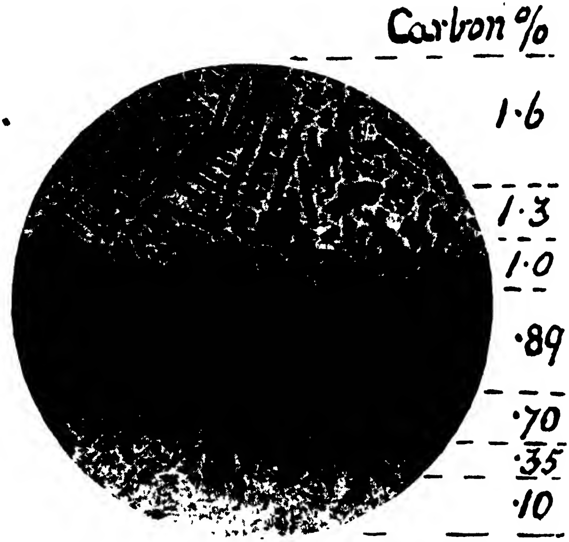


FIG. 75.—CARBONIZED ACETYLENE WELD

Through using a blow-pipe flame with an excess of acetylene it is quite easy to carbonize a weld, which means that iron or mild steel in the molten state may have carbon added to it and be converted into high carbon steel. A good illustration of this is portrayed in Fig. 75 where, in the filling of the weld, the structure of every grade of carbon content from ·10 per cent right up to 1·6 per cent can be seen. The ·10 per cent composition is, of course, of very mild steel, and this structure is shown by the white area at the bottom of the photo. The dark zone in the

FIG. 76.—WELDED TINNED IRON

FIG. 77.—ACETYLENE WELD OF TINNED IRON

centre is of pearlite which, as already mentioned, contains ·89 per cent of carbon, and the network at the top of the Fig. shows the hard carbide of iron structure together with dark areas of pearlite, the resulting carbon content being about 1·6 per cent. The surface of this weld was so hard that it could neither be filed nor machined. In passing, it may be mentioned that the use of the blow-pipe under these conditions gives us at times a very ready method of case-hardening.

Difficulty is sometimes found in welding metals that have been coated with other metals, and this is particularly so with tinned iron or steel. Careful investigation shows that the tin combines with the iron at the high temperature of the blow-pipe, and forms not only a very hard compound, but also one of large crystalline structure. This is illustrated by Figs. 76 and 77. In Fig. 76 the hard compound of the weld is shown at the right hand with the large crystals, the left being the bar with the globules of slag. Upon stressing or bending the bar slightly, fracture results, and the reason of this will be seen in Fig. 77, where the little " blocks " of the iron-tin compound are shown separated from each other, the crystals apparently being held together with very little tenacity.

Hammering of Welds. There is not the slightest doubt that the judicious hammering of either acetylene or electric welds of iron and steel immediately after they are made is a great advantage; this can be plainly seen by examining the micro-photos, Figs. 78 and 79, the former showing the structure of a steel just as welded, and the latter showing the fine grains set up by hammering. When properly hammered the weld, of course, has altogether better mechanical properties in the direction of standing, bending, or elongation. There is, however, one thing carefully to guard against, and that is the hammering of the weld at too low a temperature; this should cease

Fig. 78.—Acetylene Weld in Medium Carbon Steel Unhammered

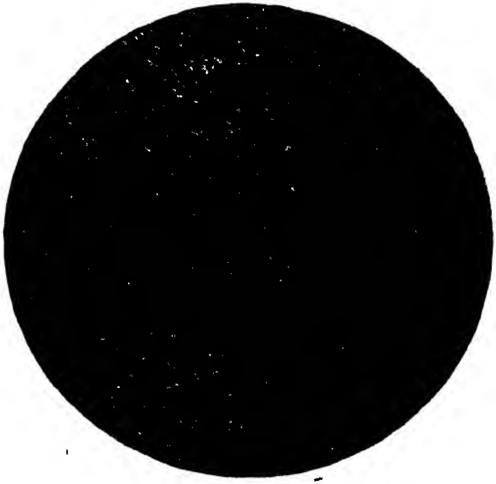


Fig. 79.—Acetylene Weld in Medium Carbon Steel Hammered

before the material comes down to a blood heat, or just when the iron regains its magnetic properties in the form of attracting a small magnet. If hammered at too low a temperature incipient fractures will be set up in the metal as shown by the micro-photo, Fig. 80.

Effects of Impure Acetylene. Blow-pipe welders ought carefully to guard against using impure acetylene, as there can be no doubt whatever that the molten metal can take up both sulphur and phosphorus from the sulphuretted hydrogen and the phosphorated hydrogen contained as impurities in the acetylene. Careful tests have been made with the results as tabulated below—

	Plate.	Filling Wire.	Weld.		Electric Arc Weld.
			Pure Acetylene.	Impure Acetylene.	
Carbon . .	·20	·08	·06	·105	Trace
Silicon . .	·04	Trace	Trace	Trace	Trace
Sulphur . .	·063	·009	·012	·10	·011
Phosphorus .	·035	·012	·011	·04	·017
Manganese . .	·40	·12	·12	·10	·05

Comparing the sulphur in the filling wire with the sulphur in the weld it will be noticed that this, through the impure acetylene, has been increased about ten times, the phosphorus also being increased about three times. Placing these results by the side of those obtained when the same filling wire is used in an electric arc, it will be seen that there has been only a very slight increase both in the sulphur and phosphorus, this, no doubt, being due to these elements passing over from the plate to the filling. Attention might also be called to the different effects on the carbon and manganese under the three methods of welding.

To show what actually takes place in a plate and weld

under electric arc welding conditions, a panorama method of taking four micro-photographs is adopted, these being

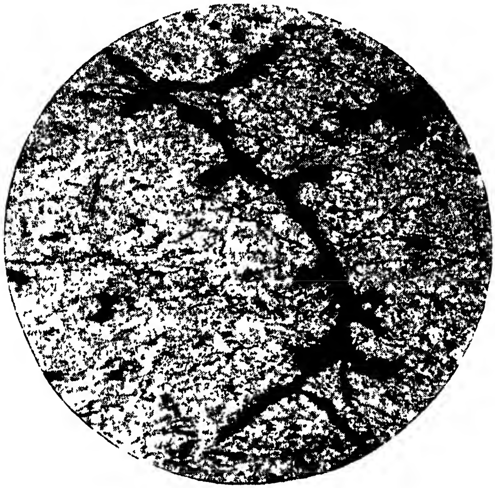


FIG. 80.—FRACTURE IN ACETYLENE WELD THROUGH HAMMERING AT TOO LOW A TEMPERATURE

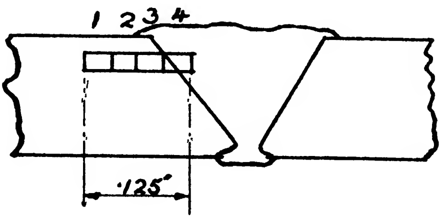


FIG. 81.—DIAGRAM OF ARC WELD SHOWING POSITIONS OF MICRO-PHOTOGRAPHS

taken from positions as shown in the diagram Fig. 81, covering a length only of $\frac{1}{8}$ in. and crossing the junction.

In No. 1 position, the structure of the plate, Fig. 82, is shown to be unaffected by the heat from the arc. At the right-hand side of No. 2, Fig. 83, it will be seen that the structure of the plate is commencing to break down slightly under heat diffusion. In No. 3 position, it will be seen

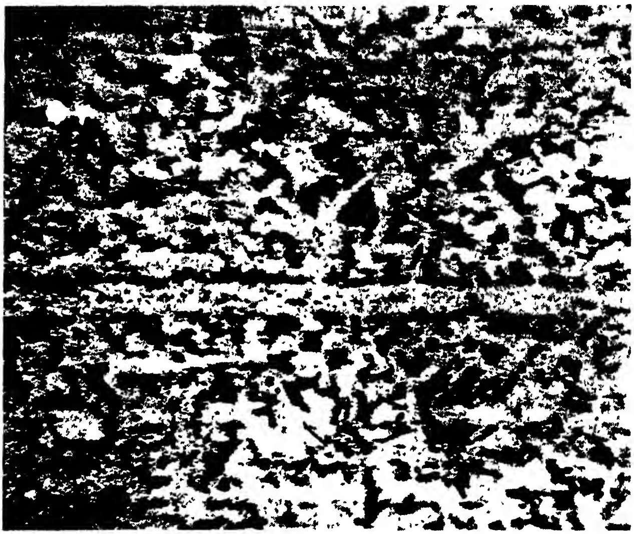


FIG. 82.—ARC WELD. PLATE STRUCTURE AT NO. 1 POSITION

from Fig. 84 that the plate structure is completely diffused whilst in No. 4 position, Fig. 85, we come to the junction and weld. Immediately to the left of the weld it will be seen that the plate shows a large grain structure due to the metal being somewhat over-heated. This group of micro-photographs clearly shows why a weld if properly made does not break at the junction, but more often pulls away at the plate on account of this being at one part in an annealed state whilst the adjoining part is somewhat

brittle. It will be noticed that the effect of heat diffusion travels to about one-sixteenth of an inch from the edge of the plate, and usually this is about one half the distance that obtains in the case of oxy-acetylene welding.

To illustrate the effects of annealing on the material,

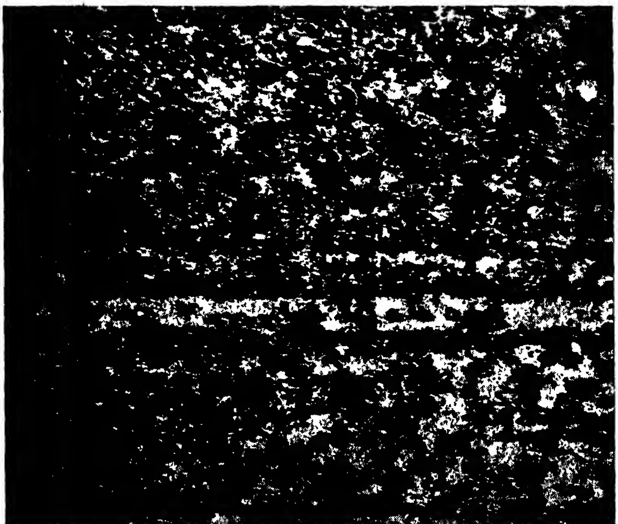


FIG. 83.—ARC WELD. PLATE STRUCTURE AT No. 2 POSITION

the weld in the last case was carefully annealed and then gave the structure as shown in Fig. 86. From this it will be observed that there is a distinct line of separation from the carbon, the black areas in the plate showing the pearlite or carbon areas, whilst in the weld above the carbon has disappeared.

A good deal has been said about the dissolving of nitrogen into the weld portion of an arc weld, and this is

certainly proved both by chemical analysis and micro-structure. Fig. 87 shows a micro-photograph of one side of a double Vee electric weld, in which small nitride needles will be noticed. To show these better a micro-photograph of the same to a magnification of 1,000 diameters is given in Fig. 88. In this the needles are plainly

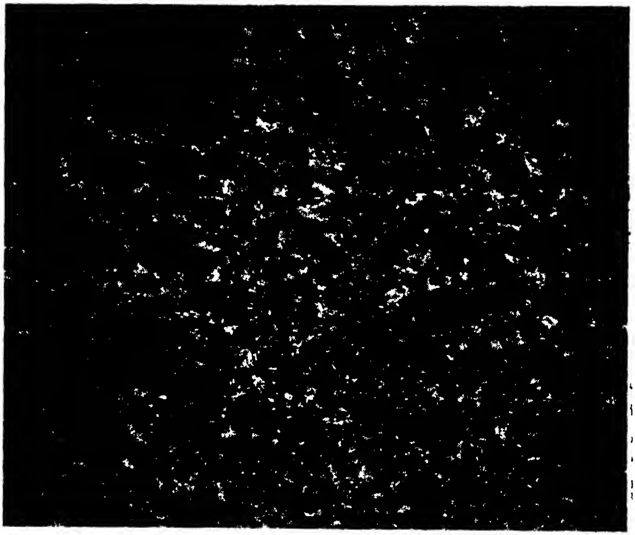


FIG. 84.—ARC WELD. PLATE STRUCTURE AT No. 3 POSITION

seen and also two small blobs of slag. Careful analysis of the weld material gave ·14 per cent of nitrogen and analysis of the electrode wire gave only about one-tenth of this amount. There can be no doubt that occluded nitrogen is a cause of brittleness. Fortunately, acetylene welders are free from this trouble.

A large number of experiments have been made by the author to find out the relative effect of electric arc and

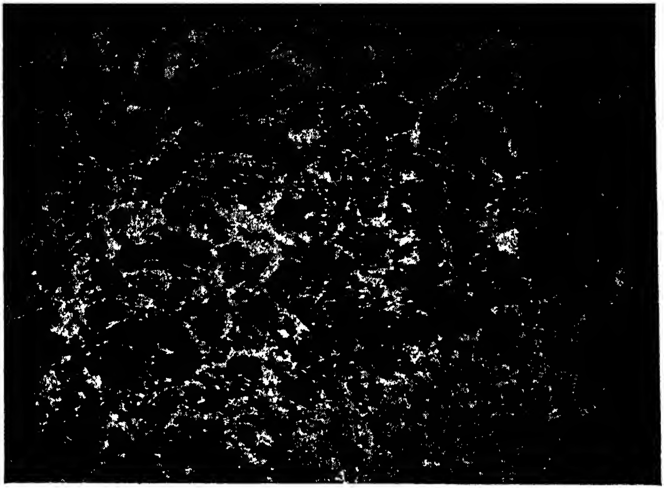


FIG. 85.—ARC WELD. SHOWING JUNCTION OF WELD AT No. 4 POSITION

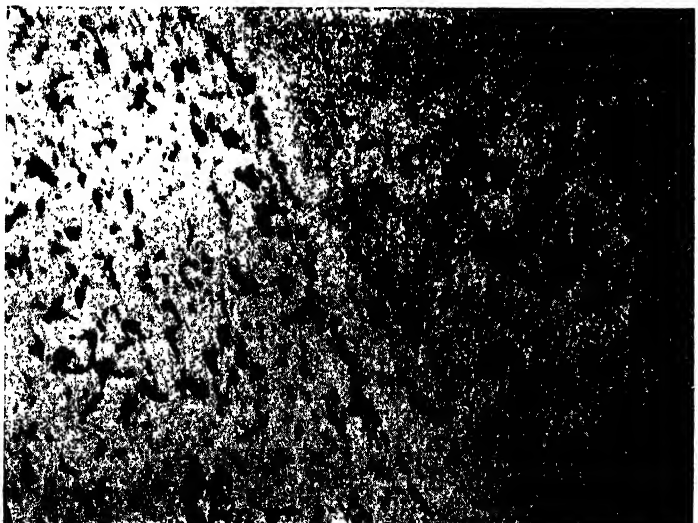


FIG. 86.—ELECTRIC ARC WELD. ANNEALED

oxy-acetylene welding on the material deposited. Some of these results are tabulated below and speak for themselves—

ARC WELD ON ¾ IN. MILD STEEL PLATE
ASBESTOS COVERED ELECTRODE

	Plate.	Filling Wire.	Weld.
Carbon	·12	·12	·038
Silicon	·047	·033	·045
Sulphur	·048	·015	·022
Phosphorus	·038	Trace	Trace
Manganese	·49	·34	Trace

Carbon loss, 68 per cent. Manganese loss, 98 per cent.
Silicon gain, 36 per cent. Sulphur gain, 50 per cent.

ARC WELD ON ¼ IN. MILD STEEL PLATE
FLUX COATED ELECTRODE

	Plate.	Filling Wire.	Weld.
Carbon	·19	·13	·12
Silicon	·18	·013	Trace
Sulphur	·034	·022	·024
Phosphorus	Trace	·014	·011
Manganese	·49	·37	·25

Carbon loss, 8 per cent. Manganese loss, 32 per cent.
Silicon loss, 98 per cent.

OXY-ACETYLENE WELD ON ¾ IN. WROUGHT IRON PLATE
NO FLUX USED

	Plate.	Filling Wire.	Weld.
Carbon	·034	·13	·08
Silicon	·12	·013	Trace
Sulphur	·023	·022	·02
Phosphorus	·068	·014	·016
Manganese	·15	·37	·13

Carbon loss, 38 per cent. Manganese loss, 65 per cent.
Silicon loss, 98 per cent.

FIG. 87.—NITRIDE LINES IN ARC WELD TO A MAGNIFICATION OF 100 DIAMETERS

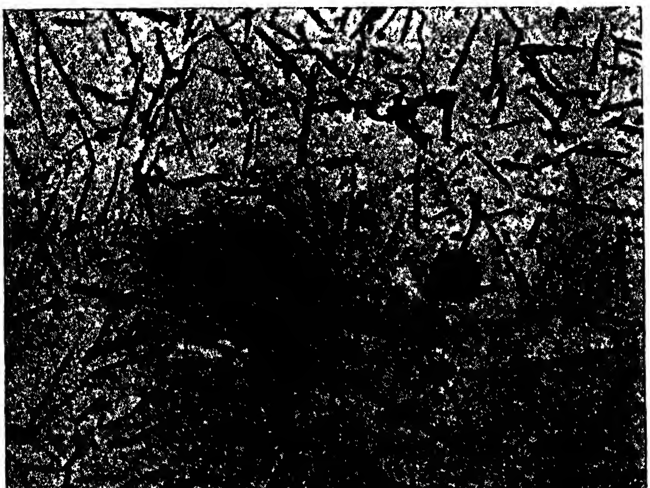


FIG. 88.—NITRIDE LINES IN ARC WELD TO A MAGNIFICATION OF 1,000 DIAMETERS

Cast Iron Welds. Before examining the structure set up in cast iron welds, it will perhaps, be as well to start with a structure of ordinary cast iron ; this is shown in Fig. 89. The light areas show the iron-silicon portions with black flakes of graphite running through them ; also there will

FIG. 89.—CAST IRON

be seen some pearlite areas containing the combined carbon, and surrounding these the network which contains the phosphorus.

The structure of an arc weld made in cast iron is shown in Fig. 90, and on this will be seen a large blow hole in the filled-in portion, manifestly caused by the gases formed through the carbon being oxidized. An edge of the blow hole is shown in Fig. 91, and this micro-photograph also explains why the arc-welded cast iron becomes so intensely hard, as the white network structure on the edge of the blow hole is composed of the hard carbide of iron, caused by the carburizing of the cast iron through the graphite

Fig. 90.—Arc Weld in Cast Iron, showing Blow Hole

Fig. 91.—Arc Weld in Cast Iron, showing Carburized Metal

going into solution. This intense hardening of cast iron in arc welding is one of the problems which has to be dealt with and, no doubt, can be solved by the use of a suitable flux under proper conditions. The junction of a weld made in cast iron with a mild steel filling by the arc system is

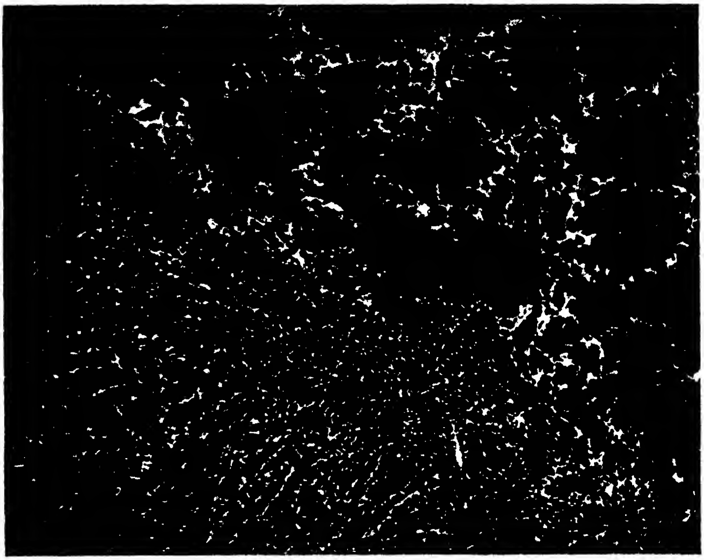


FIG. 92.—ARC WELD IN CAST IRON MADE WITH MILD STEEL FILLING

illustrated by Fig. 92. In the micro-photograph it will be noticed that complete fusion has taken place at the joint line, but here again, unfortunately, the mild steel has become highly carburized through the taking up of carbon from the cast iron.

In the welding of cast iron the oxy-acetylene process up to the present certainly shows many advantages, as by this process almost complete homogeneity at the junction

can be obtained, this being brought about by the use of a highly siliceous cast iron, the silicon performing the very useful purpose of keeping the graphite from going into solution and thus forming the hard cementite. Unfortunately, the use of this kind of filling material in the arc system results in the silicon being rapidly oxidized away. To show how uniform a structure is obtained in an oxy-acetylene cast iron weld the micro-photograph, Fig. 93,

FIG. 93.—ACETYLENE WELD IN CAST IRON

has been prepared. In this it will be observed that there is not a great deal of difference in the material on either side of the junction line.

Resistance Welds. Butt-resistance welds can be made under suitable conditions in all kinds of steel. In Fig. 94 the junction is shown of a ·80 per cent and of a ·10 per cent carbon steel welded together. Through the rapid cooling it will be observed that the ·80 per cent carbon on the right hand shows the martensitic structure, which

means that in this condition the bar on bending would break on the right hand of the joint. Careful annealing will restore the material to its proper tough condition and the remarkable change of structure that follows from this process is shown, of the same joint, in Fig. 95. On the

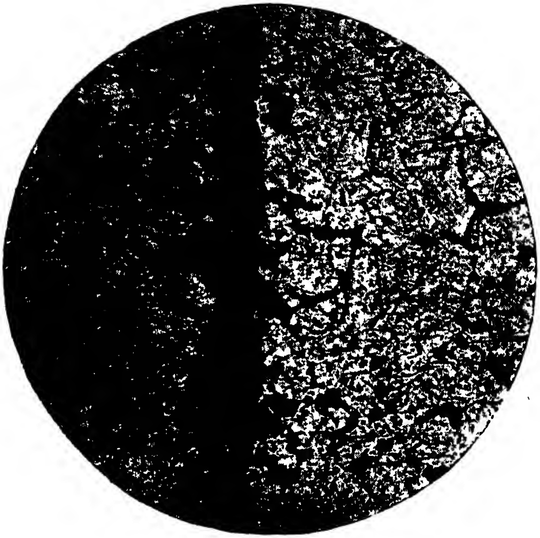


FIG. 94.—RESISTANCE WELD OF ·10 AND ·80 CARBON STEEL BAR AS WELDED

left of the junction of this micro-photograph the low carbon steel will be seen in its normal condition, and on the other side of the junction the ·80 per cent carbon steel is shown in the pearlitic condition.

The junction of a resistance weld made with two pieces of mild steel is shown in Fig. 96, the fusion in this case being so good that no line of junction is visible, the grain size is large, this, of course, resulting in hardness. The

FIG. 95.—RESISTANCE WELD OF ·10 AND ·80 CARBON STEEL BAR AFTER ANNEALING

FIG. 96.—RESISTANCE WELD OF TWO MILD STEEL BARS, AS WELDED

same joint after annealing is shown in Fig. 97, giving the characteristic structure of an annealed mild steel without showing any definite joint line, the quality of the material being practically the same as that of the steel before welding.

Foreign matter will sometimes get into the junction of a butt-resistance weld and upset its qualities, thus if

FIG. 97.—RESISTANCE WELD OF TWO MILD STEEL BARS, ANNEALED

the ends of a bar are badly rusted the oxide may not be completely squeezed out, and, if not, shows up as the black patches in the micro-photograph, Fig. 98. Perhaps one of the worst elements to be associated with welding is tin, as at the high melting point of steel this element rapidly combines with the iron and forms a hard compound. This is particularly shown in the micro-photograph, Fig. 99, being that of a resistance weld made on tinned-bar steel. In the micro-photo it will be observed there are black and white areas. The white areas show the hard

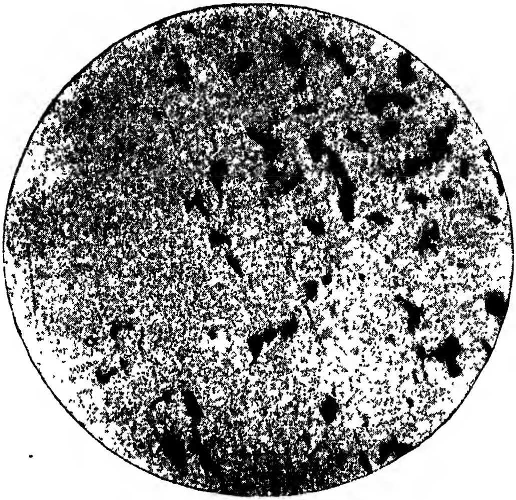


Fig. 98.—Resistance Weld containing Oxide

Fig. 99.—Resistance Weld of Tinned Iron Bars

tin-iron alloy That this compound is very brittle will be seen by the fracture shown on the micro-photo, Fig. 100, where the grains of iron are separating when the bar is slightly bent.

Contact Welding. Contact welding, in which rods and wire are welded together by simple cross contact to form

FIG. 100.—RESISTANCE WELD OF TINNED IRON BARS, SHOWING FRACTURE

fabric for reinforcing and other purposes, is now very common, and occasionally peculiarities develop in connection with same. With low carbon steel of about ·10 per cent there is no difficulty as this gives a perfect weld at the junction, as will be seen by the micro-photograph, Fig. 101, but when the material gets up to about ·20 per cent carbon, brittleness is set up in the wire or rod material adjoining the weld. The cause of this is plainly observed in the micro-photograph, Fig. 102. The white centre portion shows the junction from which the carbon has

FIG. 101.—CONTACT WELD OF ·12 CARBON STEEL ROD

FIG. 102.—CONTACT WELD OF ·20 CARBON STEEL ROD

been oxidized, whereas on the areas immediately adjoining this the martensitic structure is shown, thus setting up great hardness in the material which inevitably causes fracture. Also high sulphur and high phosphorus have a deleterious effect both in contact and resistance welding. The amounts of these elements, however, which cause defective welding vary with each other and with the carbon element.

Hard-drawn wire is also bad for contact welding, as the soft metal at the fused spot tends to strip away from the harder metal.

Spot Welding. Spot welding is now so commonly carried out that, perhaps, it will be of interest to show what takes place in the metal when two pieces of sheet are welded together. This is seen in the micro-photograph, Fig. 103, representing a section of a " spot " on two pieces of 16 gauge iron. Only a part of the welded zone is shown on which it can be seen that a small blob of oxide has been imprisoned in the centre, due to the scale on the metal, and also it will be noticed that there is a definite elliptic zone within which the structure of the metal has been affected by heat diffusion.

Welding Wire for Iron and Steel. As there is so much discussion as to whether Swedish charcoal iron is better or worse than mild steel, it will be interesting to observe the difference between the two structures of these respective materials when they both have about the same chemical composition.

The micro-structure of Swedish charcoal rod is shown in Fig. 104, on which the grains of pure iron, together with not only a slag thread, but small blobs of same are visible Fig. 105 is of a good mild steel feeding wire, and on this, while there is practically an absence of slag, there are one or two small dark areas of pearlite which, as has previously been mentioned, contains whatever carbon is present in the steel. A little reasoning will

Fig. 103.—Spot Weld in 16 Gauge Iron

Fig. 104.—Swedish Charcoal Rod

show that charcoal wire cannot possible have any advantage over a very low carbon mild steel, but rather, perhaps, through the absence of slag, the latter material would be the better of the two for the purpose.

High percentage of sulphur in feed wire is always a disadvantage, as this element is usually found in the

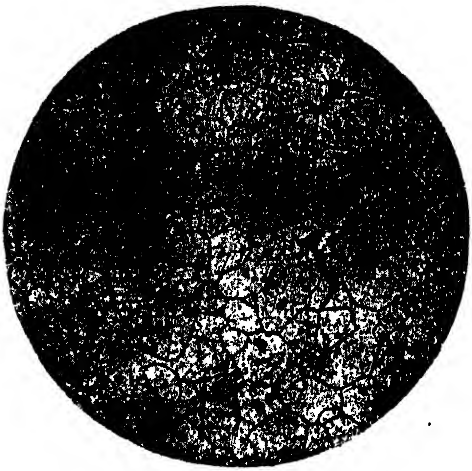


FIG. 105.—MILD STEEL WELDING ROD

steel in the form of globules or threads of sulphide of manganese, as shown on the micro-photograph, Fig. 106. These sulphides melt at a considerably lower temperature than that of the iron, and, consequently, when the high temperature of the weld is attained the sulphides are in a condition of boiling and so cause spluttering of the metal. This is also true of a high phosphorus content, and as this element as a phosphide of iron is very often in a segregated form, as shown by the white areas on Fig. 107, the same low temperature effect as with sulphur is obtained,

Fig. 106.—Sulphur in Feed Wire

Fig. 107.—Phosphorus in Feed Wire

in addition to the fact that phosphorus can only be eliminated by special means, and if not so removed causes brittleness of the joint.

A defect in filling wire which is not generally known is the inclusion of enormously large numbers of small specks of slag or oxide in the steel; these are particularly

FIG. 108.—OXIDE IN FEED WIRE

well shown by the micro-photograph, Fig. 108. On counting the number of specks on this photograph it should be remembered that they are on an area one-hundredth part of the diameter of the photo circle. Measurement and calculation have shown that some feed wires will have as many as 140,000 of these specks to the square inch, and in some steels examined it has been calculated that they contain no less than 50 millions of these small globules to the cubic inch. These specks of slag or oxide will, by intermingling with the fused steel considerably alter its nature and cause a serious disadvantage in various forms of welding.

A good deal of experimental work has been done by the author to find out the changes which take place in the composition of the deposited material after passing through the arc in electric welding, and so that the issue would not be confused it was arranged that the feed wire should have the same composition as the material upon which it was deposited. Results of a group of these experiments are tabulated below—

CHANGES IN CHEMICAL COMPOSITION OF MILD STEEL FEED MATERIAL AFTER ELECTRIC WELDING

	A		B		C		D	
	Wire.	Weld.	Wire.	Weld.	Wire.	Weld.	Wire.	Weld.
Carbon	·08	·030	·69	·040	·71	·060	·10	·04
Silicon	Trace	·010	·081	·030	·17	·16	·082	·018
Sulphur	·009	·006	·044	·019	·029	·018	·032	·006
Phosphorus	·012	·010	·068	·016	·062	·043	·018	Trace
Manganese	·12	·028	·61	·14	·84	·16	·60	·17
Nickel	—	—	—	—	—	—	—	—

	E		F		G	
	Wire.	Weld.	Wire.	Weld.	Wire.	Weld.
			(Silicon Steel)		(Manganese Steel)	
Carbon	·11	·04				
Silicon	·16	·09	4·2	2·60		
Sulphur	·017	·022				
Phosphorus	·057	·048				
Manganese	·74	Trace			11·64	9·47
Nickel	3·29	2·0				

In the welds *A*, *D*, and *E* it will be observed that about 60 per cent of the carbon has disappeared from the feed material in being deposited. In *B* and *C*, where a high carbon wire is used, it will be noticed that about 90 per cent of the carbon has disappeared, which shows

that the use of a high carbon wire under certain conditions has very little advantage over that of a low carbon material in the resulting deposit. The removal of the silicon is somewhat erratic; in some cases a large percentage has been removed and in other cases very little. With regard to the alteration in the amounts of sulphur and phosphorus, it will be seen that in weld *A*, which was carried out with an ordinary flux coated electrode, there has been very little alteration, but examination of the sulphur and phosphorus contents in welds *B*, *C*, and *D* show that there has been a remarkable reduction of these elements in the weld material in all three cases. This, it might be explained, was brought about through the use of a special what might be called anti-sulphurphos flux.

With regard to manganese, it will be seen that all the welds of the top table show a loss of about 75 per cent of the initial manganese in the feed wire.

Tests have also been carried out on one or two cases of special steel, and the results tabulated for weld *E* show that where a wire containing about $3\frac{1}{4}$ per cent of nickel had been used, about one-third of this disappeared in the welding process, whilst, rather singularly, practically the whole of the rather high (·74 per cent) manganese disappeared. Tests with a steel containing $4\frac{1}{4}$ per cent of silicon gave results of no particular value, except as showing that about 40 per cent of the silicon disappeared in the process. Tests with steel containing about $11\frac{1}{2}$ per cent of manganese showed that about 80 per cent of the original manganese was left in the deposited metal giving it the properties of steel of this high manganese content.

Material to be Welded. In carrying out welding jobs it is very often forgotten that the composition of the metal to be welded has a most material effect upon the efficiency of the resulting weld. Welders are often blamed for bad results when the defect in the weld has been entirely

due to the bad quality of the metal of which the job is composed. Cases of this description are occasionally found in connection with high phosphorus mild steel and particularly high phosphorus wrought iron, and in a piece of work recently met with the wrought iron after attempted welding gave a structure as shown on the micro-photograph,

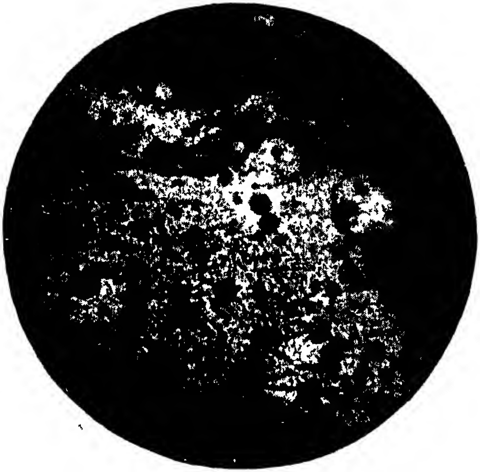


FIG. 109.—HIGH PHOSPHORUS IRON

Fig. 109. On this, large areas (white) showing the phosphoric structure can be seen. As the melting point of the phosphorus portion is low, it is immediately run into the joint with disastrous results. With this class of material a suitable flux should certainly be used.

Non-Ferrous Welds. As showing that perfect welds can be made with the oxy-acetylene process in non-ferrous metals, the following micro-photographs have been prepared.

The welding of copper is illustrated by Fig. 110 which shows perfect union at the junction. The welding of

brass is shown by Fig. 111, in which it is extremely difficult to pick out any junction line at all. Aluminium can, of course, be perfectly welded by a welder who is blessed with sufficient intelligence and experience. The structure of this type of weld is shown in Fig. 112, and like all good

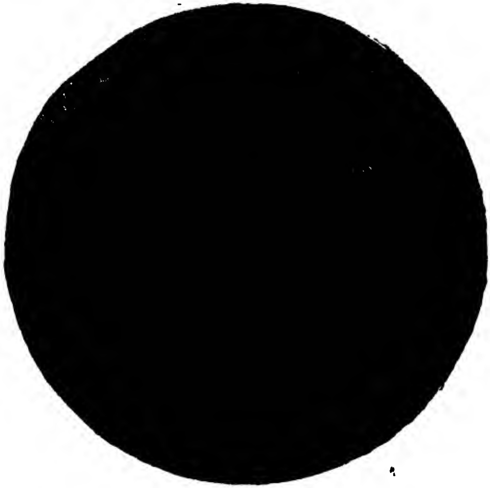


Fig. 110.—Acetylene Weld in Copper

aluminium welds, it shows complete fusion at the junction. Aluminium alloy with a suitable filling material is, perhaps, more easily weldable than the pure metal, and to show how this alloy can be properly welded, the micro-photograph, Fig. 113, has been prepared. Examination of the structure will show that there is no distinct line of separation between the filling and the plate.

Cyc-Arc Welding. This, perhaps the most recent of all methods of welding, is a combination of arc and butt-resistance welding and gives extremely good results in certain classes of work. A micro-photograph showing the joining of a brass stud on to a mild steel plate is illustrated

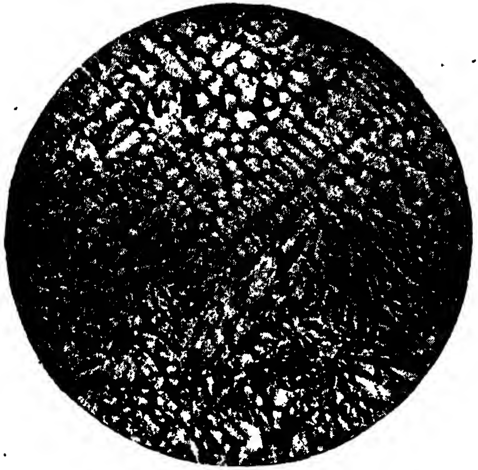


Fig. 111.—Acetylene Weld in Brass

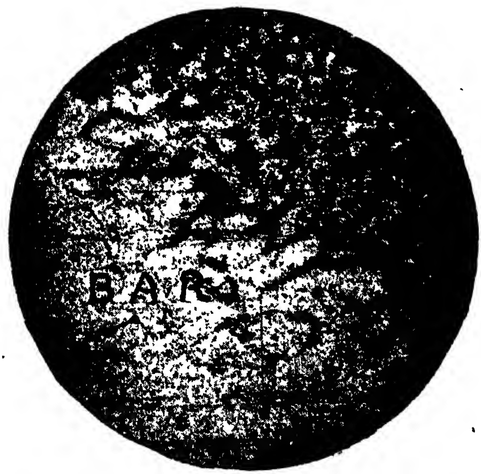


Fig. 112.—Acetylene Weld in Aluminium

by Fig. 114. On this it will be noticed that there is an intermediate band which, no doubt, is an alloy of copper and iron, and probably a trace of zinc. This band is shown to greater advantage in Fig. 115, the micro-photograph being that of the same welded joint after annealing. It hardly need be said that on account of the high temperature of the arc nearly the whole of the zinc is volatilized from the brass at the junction of the metals.

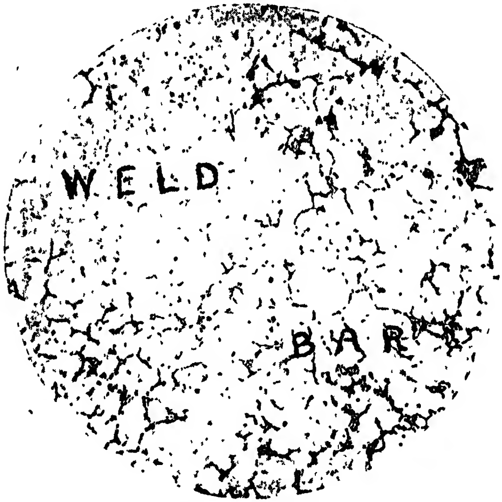


FIG. 113.—ACETYLENE WELD IN ALUMINIUM LIGHT ALLOY

The joining of dissimilar metals is no new thing in welding, as there are a small number of expert acetylene welders who make extremely good jobs in the uniting of all kinds of metals and alloys, both to themselves and to each other.

In conclusion, from what has been said above, it will be seen that there is more in the art and practice of the welding of metals than appears on the surface, and for

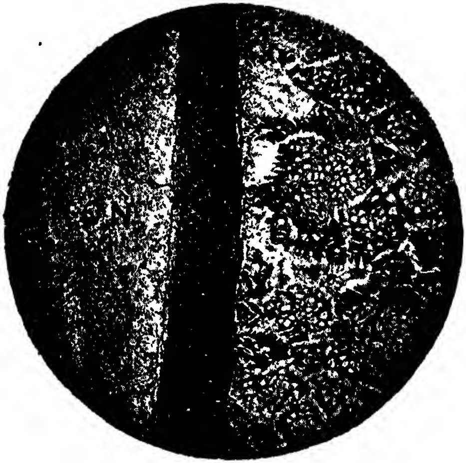


FIG. 114.—CYC-ARC WELD OF BRASS ON IRON—AS WELDED

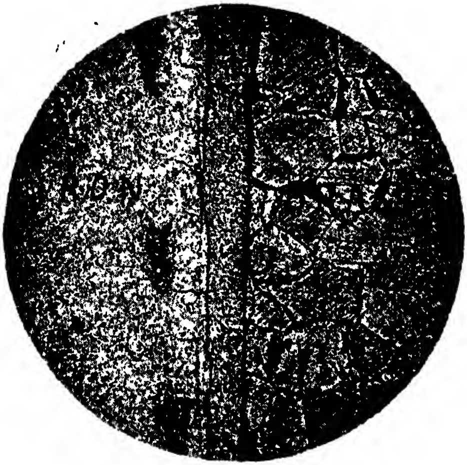


FIG. 115.—CYC-ARC WELD OF BRASS ON IRON—ANNEALED

the various processes to advance in usefulness as they ought to do, it is necessary for a good deal of investigation work to be done. In addition, it is essential that the proper training of welders should be carried on along the best lines of instruction, and that certificates of competency should only be granted to operators after the fullest test of their capabilities.

CHAPTER XVI

FEED WIRES, RODS, ELECTRODES, AND FLUXES

There is nothing in connection with welding about which there is so much uncertainty and dispute as welding rod or wire. What one operator regards as good welding wire, another rejects as useless, and bad welds of all descriptions are more often than not put down to inferior welding wire. Filling wire is generally classified as being "soft" or "hard," the latter being rejected on account of its supposed unsuitability for welding purposes. If the term "soft" meant only those steels which contain low percentages of their non-ferrous constituents all would be well, but this is not so, the quality of the wire for welding being usually judged by its ease in bending. There is some excuse in this method of testing for old time welders, as these had been trained to use nothing but soft Swedish charcoal wire, and had got into the habit of judging its suitability by the simple test of bending. In these days when a mild steel can be produced with as high or a higher degree of purity than charcoal iron, there is not the same use as formerly for the application of the old-fashioned bending test.

If the bending test is applied to a mild steel rod just as it comes from the rolling mill before wiredrawing, then the hardness or softness of the material is a rough test as to its suitability for use in welding, but as wire is very rarely used in this form, the test is of little avail in ordinary practice.

It cannot be too widely known that the stiffness of a drawn wire can be carried up to almost any degree depending upon the method of wiredrawing, size of resultant wire, etc. For instance, a mild steel rod of about 25 tons tensile

strength can be quickly run up to a strength of 50 tons with corresponding hardness by wiredrawing without any alteration taking place in its chemical composition. When run into a weld this steel would have the same properties as a similar wire which had been made dead soft by annealing. What is of paramount importance is that a welding wire should show the best chemical analysis for the work for which it is required, and that its surface should be free from oxide or other foreign matter that will affect the physical properties of the weld.

Before dealing with the results of any tests on filling wire, it should be remembered that the quality of a weld depends upon the following factors—

(1) The quality of the operator.
(2) Method of treating the weld after welding.
(3) The quality of the acetylene used.
(4) The quality of the plate to be welded.
(5) The quality of the feed wire.

(1) Quality of the Operator. The most important factor in connection with welding, there can be no doubt whatever, is the operator, for given identically the same conditions for two different welders, very often two entirely different results can quite easily be obtained. Generally it is only after a fairly long training that an expert welder can be made, the length of time required, as a rule, being inversely proportional to the amount of intelligence and interest he displays in connection with the process.

(2) After Treatment of a Weld. The strength and ductility of a weld can be very much altered either by annealing or hammering where these operations can be carried out. Hammering at the right temperature entirely alters the size of crystal in the filling material, and this again considerably affects the toughness and strength of the joint.

(3) The Quality of Acetylene. Several tests have been very carefully made as to the effects of pure and impure

acetylene on the chemical composition of the material deposited in a welded joint, and for the sake of comparison, an electric arc weld was at the same time made on the same plate and from the same feed wire. The results of analyses are tabulated below—

	Carbon.	Silicon.	Sulphur.	Phos.	M'ng'nese.
(a) Plate	·20	·04	·063	·035	·40
(b) Filling wire . .	·08	Trace	·009	·012	·12
(c) Weld (pure acetylene) .	·06	—	·012	·014	·12
(d) ,, ,, ,,	·06	—	·012	·008	·12
(e) Weld (impure acetylene)	·05	—	·080	·039	·11
(f) ,, ,, ,,	05	—	·102	·027	·09
(g) Electric arc weld . .	Trace	—	·011	·017	·05

In carrying out the above tests the plate chosen was $\frac{1}{8}$ in. thick with an analysis as shown in the table.

The plate was Vee'd and the feed wire deposited considerably above the level of the plate so as to obtain a sufficient quantity of the metal for purposes of analysis, and also as far as possible to avoid having the composition of the jointed metal contaminated by that of the plate.

Filling Wire. The filling wire chosen was that of a well-known brand, this was then analysed and also a micro-photograph taken of its cross section to a magnification of 100 diameters. This is shown in Fig. 116. The analysis, as will be seen from line (*a*) in the table, shows the material to be very pure and eminently suitable for welding purposes. This is also borne out by the micro-photo. The very few small black areas show the pearlite containing the small amount of carbon proved to be present by analysis.

Welds Made with Pure Acetylene. Two welds were made by an experienced operator and the deposited metal in each of them analysed, with the result shown on lines (*c*) and (*d*) in the table. It will be noticed that there has been a loss of 25 per cent of the carbon and an increase in the sulphur in both cases, and a slight increase

in the phosphorus in one case, and a decrease in the other, the manganese remaining the same as the filling wire. The change both in the sulphur and phosphorus is no doubt due to a little of these elements passing from the plate to the filling. A micro-photograph of the structure at junction of plate and weld is shown in Fig. 117. It will be seen that the joint is quite homogeneous.

FIG. 116

WELDS MADE BY IMPURE ACETYLENE. Two welds were made by the same welder using unpurified generated acetylene, and when the deposited metal was analysed the difference in the composition of the material as compared with the filling wire was found to be most remarkable. Line (*e*) in the table shows that the sulphur has increased nine times, and the phosphorus three times, whilst in the weld (*f*) the sulphur has increased eleven times, and the phosphorus more than doubled. There has also in each

Fig. 117

Fig. 118

case been a slight reduction in the carbon and in the manganese.

A micro-photo of one of the welds which had been broken is shown in Fig. 118, in which it will be noticed that the fracture has taken place along the line of impurities. As would be expected from the above results, the weld made from dissolved acetylene gave the best physical tests, the efficiency of the joint (*c*) being 90 per cent and that of (*d*) 100 per cent, whilst the efficiency of (*e*) is down to 80 per cent and that of (*f*) down to 40 per cent, the latter being rather badly oxidized. It need hardly be said that the bending qualities of (*c*) and (*d*) were considerably better than those of (*e*) and (*f*).

Electric Arc Weld. For the sake of comparison an electric arc weld was made from the same plate and filling wire, the deposited metal being analysed with the result shown on line (*g*) of the table. It will be noticed that the carbon has practically disappeared, also that about 60 per cent of the manganese has passed away. There has been a slight increase both in sulphur and phosphorus, these no doubt being altered by additions from the plate.

A micro-photograph of the electric weld is shown in Fig. 119, in which the Vee of the plate is plainly visible, showing complete union between the metal of the plate and filling. In this case careful examination of the weld will bring to light the now well-known nitride lines which are commonly found in arc welds. Although there was such good fusion in this joint, its bending qualities were exceedingly poor on account of brittleness, the latter being due to the dissolved nitrogen.

(4) **Quality of Plate.** Without the greatest care in welding, the quality of plate, if of poor composition, is certain to affect the quality of weld, and a welder before blaming the feed wire should be careful in the first instance to find out whether the trouble of brittle joints is not due to running too much of the plate into the weld, which will

certainly undo the good qualities of a first class filling wire.

Many tests have been made as to the effect of plate material on the chemical composition of the deposit,

FIG 119

and in cases where the joint has developed excessive brittleness it has always been found that the deleterious elements in the plate steel had been carried into the joint. Thus, in one case where the plate showed a very high phosphorus content of ·18 per cent, it was found that the phosphorus of the filling material had been lifted up from ·04 per cent in the wire to ·10 per cent in the deposited material.

(5) Quality of the Feed Wire. From the above it will be seen how readily molten steel absorbs sulphur and phosphorus, and the deleterious effect these elements have

upon the weld. It will also be noticed that the quantities of sulphur and phosphorus in the feed wire are not at all reduced either in acetylene welding or electric arc welding.

A further test on a $\frac{3}{4}$ in. wrought iron plate with a different filling wire gave similar results, the analysis being as follows—

	Plate.	Filling Wire.	Weld.
Carbon . . .	·034	·130	·080
Silicon . . .	·120	·013	Trace
Sulphur . .	·023	·022	·022
Phosphorus . .	·068	·014	·016
Manganese . .	·150	·370	·130

In this weld it will be seen that there has been a loss of 38 per cent carbon, 65 per cent manganese, and nearly the whole of the silicon, but here again it will be observed that the sulphur and phosphorus of the filling wire has not been at all reduced.

Many other tests have been made using filling wire with varying percentages of phosphorus and sulphur, but in every case it has been found that these two elements persist in the weld deposit.

Seeing that both sulphur and phosphorus so detrimentally affect the quality of a weld, it is only common sense to start out with a feed wire which contains only small percentages of these evil constituents.

For a good filling wire that is to be used without flux in an uncoated state, it is a great advantage for it to have low carbon so as to have as small a quantity of this as possible to be oxidized away in the form of carbon dioxide, and it is essential that both the sulphur and phosphorus should be as low as is practicable on account of these elements causing not only "boiling" in the molten metal, but also a resulting bad joint.

The composition of a filling wire to be aimed at should

have its constituent elements not greater than the following—

Carbon		·13
Silicon		·02
Sulphur		·04
Phosphorus		·04
Manganese	Gas, under	·30
Manganese	Electric, over	·50

Users of welding wire sometimes have all kinds of fads and fancies with regard to the composition that gives the best result, but a welding wire that approximates to the analysis shown in the table is almost a perfect quality of wire for carrying out successful welding. It would certainly pay buyers of welding wire to insist on knowing something of the material they are obtaining and not to be put off with wire which would be more suitable for the construction of a cattle fence than for welding purposes. This latter statement may seem somewhat extravagant, but the author having analysed so-called welding wires of every description can speak with some authority as to the kind of material that is often sold to welding firms.

The following table shows how iron and mild steel wires differ in composition when they have not been specially made from suitable iron or steel. The twenty analyses shown have been obtained by actual analysis of samples of welding wire and electrodes obtained from various sources—

ANALYSES OF WELDING WIRES

No. of Sample.	1	2	3	4	5	6	7	8	9	10
Carbon	·02	·02	·03	·05	·05	·08	·10	·10	·11	·09
Silicon	Trace	·005	·025	Trace	·02	·005	Trace	·018	Trace	Trace
Sulphur	·04	·025	·004	·055	·008	·046	·03	·02	·047	·041
Phosphorus	Trace	·005	·04	·024	·047	·088	·02	·016	·007	·020
Manganese	Trace	·025	—	·47	—	·42	·51	·36	·27	·32
No. of Sample.	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**
Carbon	·06	·12	·136	·14	·14	·15	·16	·20	·23	·26
Silicon	Trace	·033	·110	·03	·108	·08	·05	·008	Trace	·06
Sulphur	·02	·015	·03	·042	·026	·09	·047	·025	·038	·05
Phosphorus	·016	Trace	·015	·065	·01	·10	·036	·005	·078	Trace
Manganese	·17	·34	·35	·38	·40	·38	·52	·50	·34	·45

Nos. 1, 3, and 5, it will be seen from the analyses, are iron, all the rest being mild steel. Examination of the seventeen mild steel wires or electrodes, which were taken at random from various sources, shows a wide variation in composition.

For acetylene welding the wires which contained carbon below ·12 and were low in sulphur and phosphorus were found to be suitable for ordinary classes of iron or mild steel work. The exception in the case of welding thin sheet, where for three reasons the higher carbon wires of Nos. 16 to 18 were generally preferred. The reasons are—(1) the higher the carbon content the lower the melting point of the wire. (2) With thin sheet the heat is not conducted and radiated away so rapidly as with plate, therefore it is more local and brings the sheet up to the melting point quickly ; the higher carbon wire just suiting this condition. (3) The higher carbon wire not being so sluggish as the lower carbon quality enables the speed of welding to be greater.

With higher carbon wire there is always the disadvantage of slightly more sparking through the oxidizing of the carbon and as this comes away in the form of the gas carbon dioxide there is dangér of welds being porous.

High sulphur is a greater disadvantage in a welding wire, as this element in the steel exists in the form of pockets or threads of manganese sulphide (*see* micro-photo in chapter on "Testing of Welds") and as this compound melts at a comparatively low temperature, it readily boils and splutters at the high temperature of the blow-pipe flame, making it difficult to obtain a solid weld.

Phosphorus, too, very often exists in steel in a segregated form (*see* Chapter XV) the element combining with only a small quantity of steel to form a low melting compound ; this again causing spluttering. Phosphorus also causes brittleness in the weld. Phosphorus and sulphur generally should not exceed ·04 per cent.

Whilst the analyses in the table do not show it, there is generally found in steel other elements which influence the welding properties of wires and electrodes, these being nickel, copper, tin, oxygen, hydrogen, and nitrogen. Also occasionally through the introduction of unknown scrap into the steel furnace, chromium and tungsten may be found.

Nickel is the commonest extra element to be found, often to the extent of ·1 to ·2, and this generally assists the metal to flow in a clean manner. Some welding wires are coated with this metal, and as a rule these give good results but at rather a big cost. The presence of nickel in steel gives the latter metal the property of being able to keep in solution gases which if freed would make a welded joint porous.

Chromium in wire generally makes it run somewhat gritty, and tin, which may be present up to ·2 per cent, certainly makes the weld metal brittle (*see* Chapter XV).

The presence of hydrogen in steel is always to the good, as being a reducing gas it helps to retard the formation of oxide, and thus assists the weld metal to run clean.

Hydrogen may be actually put into weld wires by allowing them to be immersed in dilute sulphuric acid for a short time immediately before they are required to be used.

For electrodes the higher manganese of ·50 or a little more is an advantage to the resulting deposited metal.

With some systems of electric welding the higher carbon rod of about ·20 can be used, but the operator should be guided by the instructions issued with the particular plant.

Special rods and wires for electric welding are used in connection with particular classes of work. Generally these are steels that are either high in carbon, nickel, or manganese.

Rods for Cast Iron. For the acetylene welding of cast iron a ferro-silicon rod is used, the best amount of silicon

being about 3 per cent. Analyses of two rods are as follows—

	No. 1.	No. 2.
Graphite	2·31	2·52
Combined Carbon	·61	·64
Silicon	3·035	2·33
Sulphur	·044	·01
Phosphorus	1·13	·30
Manganese	·56	·15
Titanium	·25	None

For the electric welding of cast iron the ordinary low carbon mild steel rod can be used. But the success of the welding turns upon the kind of coating on the electrode and the manipulation of same.

Welding Wires for Copper, Brass, etc. For the welding of copper a phosphorus copper rod or wire is used. Only about ·3 per cent or less of phosphorus is found in the wire. This element has already done good work in freeing the copper of the wire from oxide, and in the weld the remaining phosphorus may all disappear in reducing the oxide and carrying away in the slag, the product formed.

For the welding of brass a filling wire containing a small amount of aluminium is used, this metal also acting as a deoxidizer, as it does in many other metallurgical processes.

For aluminium a wire of the same metal is used, and for aluminium-alloy a special alloy rod.

Fluxes. Powdered fluxes are put up and sold to suit different classes of work, and it is generally safer for an operator to buy a flux than attempt to mix it himself. For the acetylene welding of cast iron the two following fluxes have been used—

(1)	Carbonate of Soda	42 per cent
	Bicarbonate ,, ,,	42 ,, ,,
	Borax	12 ,, ,,
	Precipitated Silica	4 ,, ,,
(2)	Carbonate of Soda	50 per cent
	Bicarbonate ,, ,,	50 ,, ,,

Fluxes for aluminium are very varied, but they are usually compounded from the following—Potassium chloride, cryolite, calcium chloride, sodium chloride, lithium chloride, potassium fluoride, sodium bisulphate, and potassium bisulphate.

For copper and brass, sodium chloride, sodium borate, and boric acid have been used, together with powdered glass.

For malleable castings, manganese bronze and Tobin bronze, borax can be used.

Coated Electrodes. These are sold with either a thick or a thin coat. The lagging of the heavily coated wires is usually composed of asbestos in some form together with other compounds. Kaolin or China clay is also used. Heavily coated electrodes should be used in all overhead work, and the same applies when alternating current is used.

Thinly covered electrodes may have the least wash of a flux on them or may be coated with a paste.

All kinds of solutions and pastes have been used to make up coating compounds, of which the following are a few—

FOR MILD STEEL.

No. 1.	Lime	65 per cent
	Silica	35 ,, ,,
No. 2.	Lampblack	50 per cent
	Borax	10 ,, ,,
	Aluminium Powder	5 ,, ,,
	Powdered Chalk	30 ,, ,,
	Sodium Ferrocyanide	5 ,, ,,
No. 3.	Lampblack	50 per cent
	Pyrogallic Acid	5 ,, ,,
	Aluminium Powder	5 ,, ,,
	Borax	10 ,, ,,
	Powdered Chalk	30 ,, ,,

FOR CAST IRON.

No. 1.	Bicarbonate of Soda	40 per cent
	Carbonate of Soda	40 ,, ,,
	Borax	15 ,, ,,
	Precipitated Silica	5 ,, ,,

No. 2.	Bicarbonate of Soda	20	per cent
	Carbonate ,, ,,	20	,, ,,
	Lampblack	40	,, ,,
	Borax	15	,, ,,
	Precipitated Silica	5	,, ,,

FOR ALUMINIUM.

Sodium Chloride	12	per cent
Sodium Fluoride	33	,, ,,
Potassium Chloride	55	,, ,,

Also flux pastes have been made from the compounds named in connection with blow-pipe welding.

CHAPTER XVII

THE CRYSTALLIZATION OF METALS

MILD AND HARD STEELS

The study of the crystallization of matter is of a most fascinating character, and from the practical point of view of great importance to the welder. All substances

Fig. 120

can be made to pass through the three states of either solid, liquid, or gaseous, under suitable conditions of temperature and pressure. There is, however, another way in which materials can be classified so far as their

physical condition is concerned, and that is according as to whether they are crystalline or non-crystalline in character.

Substances which crystallize are those, it may be said,

FIG. 121

which follow some regular form or order. Those which are non-crystalline or amorphous are those which follow no regular form. The first condition may be likened to an army of soldiers standing in regular formation, whilst the latter can be compared to a mob or crowd of people.

It may be explained that crystal growth is of a different order to organic growth, the former taking the form of addition, whilst the latter is by chemical change and absorption.

The formation of grains into geometrical shapes may be illustrated by the crystallization of snow, various salts, metals, etc., and amongst these nothing can be seen under the microscope which better illustrates grain growth

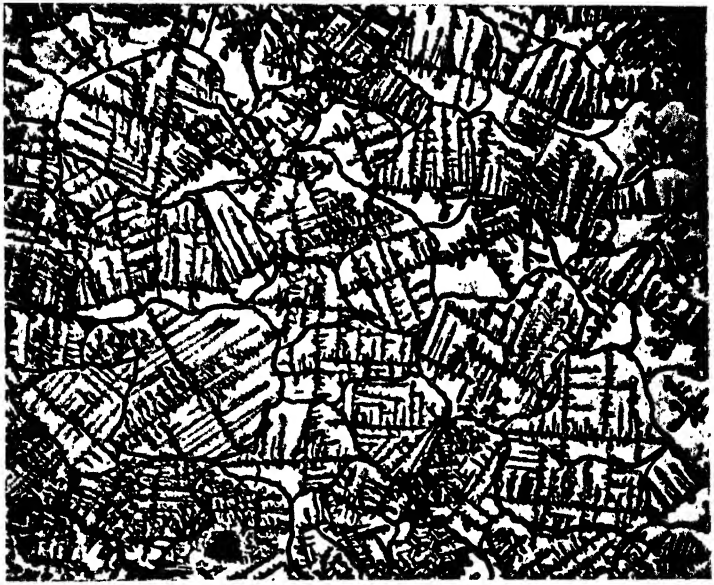


FIG. 122

than the crystallization of salammoniac from a solution of suitable density Fig. 120 shows the crystallizing out under the microscope, and dendritic growth, of salammoniäc in a rather weak solution, the magnification being to 100 diameters. The grains are formed by the branches of the crystalline " trees " growing out until they fill up the space between each other as shown in Fig. 121. The junction of the " trees " form the boundaries of the grains,

this being shown by Fig. 122 which is identically the same micro-photograph as Fig. 121, with the exception that the junction of the grains have been marked in. The grains in steel are formed in some such manner as that illustrated by the chloride of ammonium.

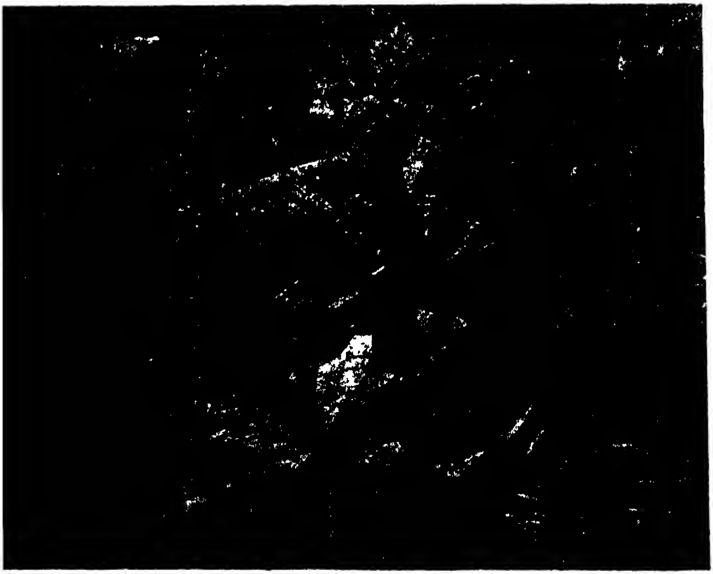


FIG. 123

Crystallization is further illustrated by the spangle formation on the surface of a well galvanized sheet, Fig. 123 and the peculiar crystalline structure set up on the surface of a sheet of tin when dipped in dilute nitric acid, Fig. 124. Carbide of calcium also showed a distinct crystal formation, Fig. 125, the sample for this being prepared by careful dry, fine polishing, then instantly being placed under the microscope and a micro-photograph taken to a magnification of 100 diameters. It is interesting

to watch the surface of the carbide whilst under the microscope, as the giving out of acetylene and the formation of lime seemed to initially take place at the grain boundaries, this being well illustrated by the micro-photograph, Fig. 126, which was taken two minutes after the first. In each

FIG. 124

of the micro-photographs the grain with X on it is identical. A careful comparison of the two micro-photos show the commencement of the formation of lime on the second, this being particularly pronounced about the top of the centre grain.

What is Steel? The quick and rough answer is that mild steel is composed of about 99½ per cent of iron together with a half of one per cent of impurities, which means to say that if we have a coil of wire of 200 lbs. weight, it

contains 199 lbs. of iron together with 1 lb. of impurities or other matter. Hard steel is composed of about 98½ per cent of iron together with about 1½ per cent of other constituents, so that in a coil of wire 200 lbs. weight there would be about 197 lbs. of iron together with about

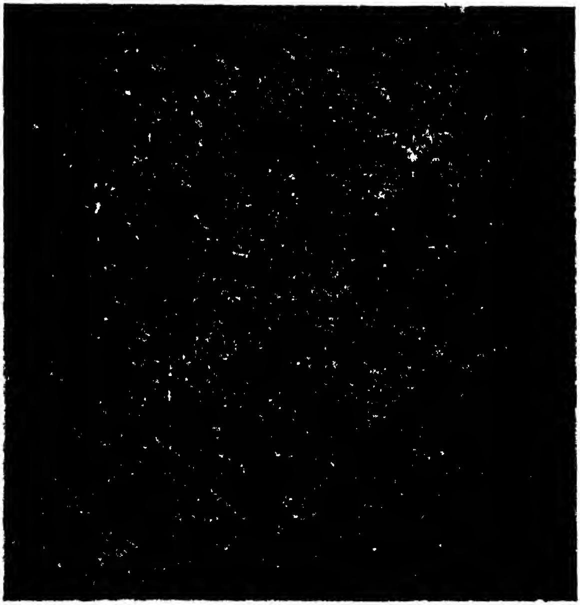


FIG. 125

3 lbs. of other kinds of matter. The answer seems simple on the surface, but it does not tell us very much about the steel. As a matter of fact, all steels can be considered to have a rock-like formation, and to be built up of crystal grains.

After the making of steel, and when it cools down from the fluid or molten condition to the solid state, it changes

very much in the same way as water changes into ice; little crystal grains form, and then join together to make bigger crystals, just as the tree-like shape is formed in the freezing of water.

Fig. 127 shows a micro-photograph exhibiting the

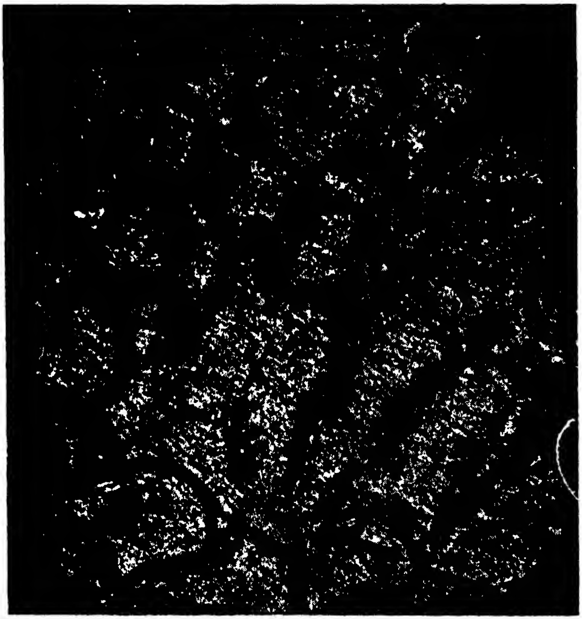


FIG. 126

crystal grain formation in a piece of "Rylax" welding wire, which is almost pure iron, the surface of the specimen being first ground, highly polished, and then lightly etched with acid to bring up its structure. It is shown magnified a hundred times across or ten thousand times altogether, which will give some idea of how very

small these grains are. Perhaps a better way to appraise the magnification is to look upon the real size of the area magnified as being just about that of a dot over one of the "i's" on this page.

It will be noticed that the crystal grains all dove-tail into each other like blocks of masonry, and if each one

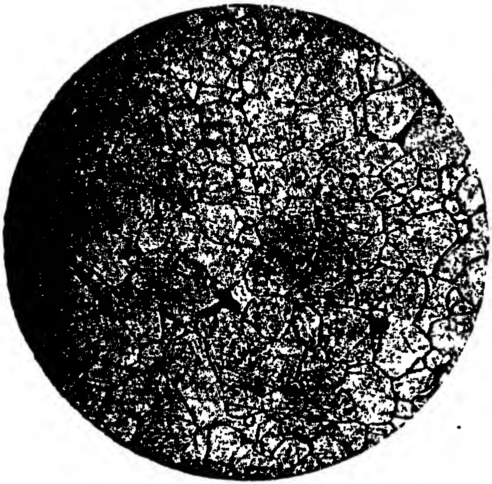


FIG. 127

had been free to form its own shape they would all have been regular in form, but as the steel has cooled down the grains have jostled each other like people in a crowd, and thus have not been free to shape themselves in a regular way, and have been obliged to take this irregular form and fit in with each other as best they can. It is an exceedingly interesting question as to what it is that keeps the crystal blocks so tightly cemented together.

If it were possible to see these little grains jumping through the hole of the wire-drawer's plate as a piece of wire was passing along, we should see about a million of

them fly through on every inch length of the wire, and as they pass through each little crystal would receive a squeeze that would make it a bit thinner and somewhat longer.

The impurities in mild steel amounted to about half of 1 per cent, and in hard steel to about $1\frac{1}{2}$ per cent. What are these impurities or constituents? Usually they are carbon, silicon, sulphur, phosphorus, and manganese. The one we are particularly concerned with at the moment is that known as carbon, as this is the particular ingredient which has the most wonderful effect on the properties of steel, determining the degree of softness, hardness, and strength. It seems a somewhat remarkable fact that whilst one steel, which contains about 2 ozs. of carbon to 100 lbs. of the steel, should be soft, another steel, which has about 10 ozs. of carbon, is hard and has entirely different properties. Carbon is a very common material and well known to everyone under the form of coke, soot, blacklead, and that which is not so commonly handled, the diamond; this being the purest form of carbon.

Fig. 128 shows a micro-photo of mild steel containing about 3 ozs. of carbon to 100 lbs. of iron, and it is peculiar to notice that the carbon does not intimately mix with iron. The little black areas in between the crystals contain all the carbon, but it should be definitely understood that these black areas are not carbon in themselves, but are a compound of iron and carbon containing ·89 per cent, which is about one part of carbon in 110 parts of the steel. The black appearance, it might be pointed out, is caused through the specimen of metal being polished and then etched, the etching process particularly darkening the little areas where the carbon is contained.

As the steel increases in the amount of carbon it possesses, then the black areas get larger and larger, and the white areas very small, in fact these areas contain all the carbon

and with exactly the same per cent, namely, ·89, the white areas being nearly pure iron, as in Fig. 127.

To show how the black areas increase and the white areas get less, a micro-photograph (Fig. 129) is shown of a piece of ·57 per cent carbon steel. Although this steel

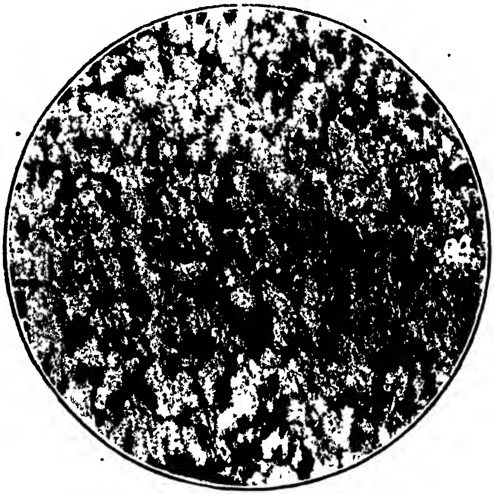


FIG. 128

contains only 9 ozs. of carbon to every 100 lbs. of its weight a distinct difference is noticed in the structure from that shown in Fig. 128. The black areas have considerably increased, whilst the white areas have now become a net-work, only enclosing the parts which contain the carbon.

The white areas in Figs. 128 and 129, it should be remembered, are practically pure iron, the only difference being that the amount of free iron in the hard steel is very much less than in the case of the mild steel. In passing, it will not be out of place if we take note that the white areas in steel have given to them the name of " Ferrite,"

because it is almost pure iron, whilst the black area constituents are spoken of as "Pearlite," because of its pearly appearance when light shines upon it.

It will thus be seen that when steel freezes from the molten condition and becomes solid, it passes through

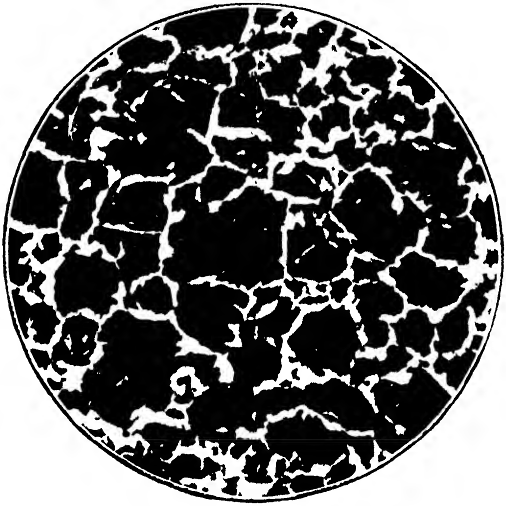


FIG. 129

very peculiar changes, all the little crystals acting almost as if they were endowed with life, and fixing themselves in some form, according to their likes and dislikes. It will also be noticed that the greatest amount of carbon which the iron will dissolve is ·89 per cent, and if there is more iron present than is required to form this, the iron separates out in the form of the thick or thin net-work of white crystals.

To show the gradual change which takes place in the structure of steel as the carbon increases, the set of micro-photos, Fig. 130, have been taken, these showing the

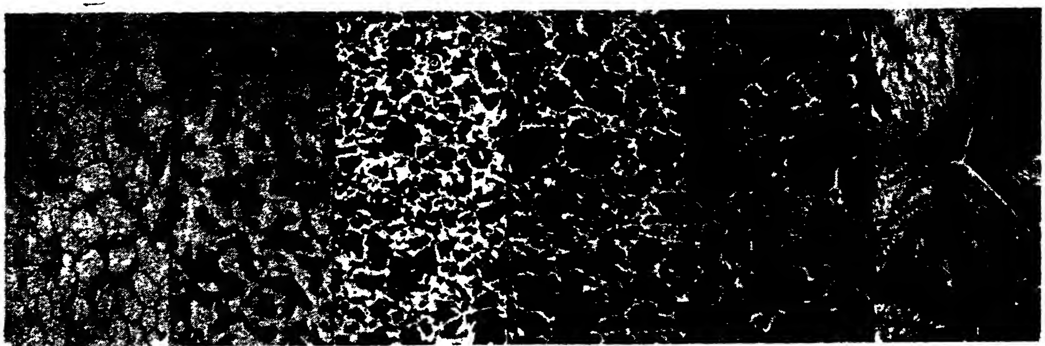
structures of steels with carbons varying from ·20 per cent to ·85 per cent; the steels being in the normal condition as they came from the rolls.

The Effect of Heat and Cold on Mild Steel. The effect of change in temperatures on the internal structure of mild steel is quite remarkable. In days gone by, when a piece of steel was gradually heated or suddenly cooled, one could only try to imagine the kind of alteration that was taking place amongst the crystals or molecules of the material. But in our day, such great strides have been made that with photographic accuracy we can determine something of the changes that are going on as a piece of steel is either heated up or cooled down. Just as a cinema photographer by standing in a school playground can photograph all the changing forms that the children assume in drill and play, as they scamper about under the orders of teacher, or move by their own sweet will, so the metallurgist with his microscope is now able, in some measure, to look into and record the varying changes that take place in the internal structure of a piece of steel which are set up under the influence of either heat or cold.

No. of Test.	Time of Heating in Minutes.	Highest Temperature. Centigrade.	Time held at highest Temperature in Minutes.	Time of Cooling in Minutes.	Tensile Strength Tons per square in.	Elongation per cent in 2 ins.	Twists in 8 ins.
1	Wire as drawn	—	—	—	64·43	2·5	46
2	15	540	15	50	34	12·5	80
3	25	600	25	50	28·25	20	103
4	60	735	10	60	25·46	25	117
5	120	840	10	60	25·2	22·5	126
6	120	900	10	100	25·25	22·5	142
7	130	1,010	10	130	25·05	22·5	88

Perhaps it will be interesting to follow the changes that take place in a piece of 16 gauge mild steel wire as it is heated up to various temperatures, and for this purpose a piece of wire made of ·12 per cent carbon steel

1 2 3 4 5 6



CARBON PERCENTAGES—

·20 ·35 ·45 ·58 ·75 ·85

FIG. 130

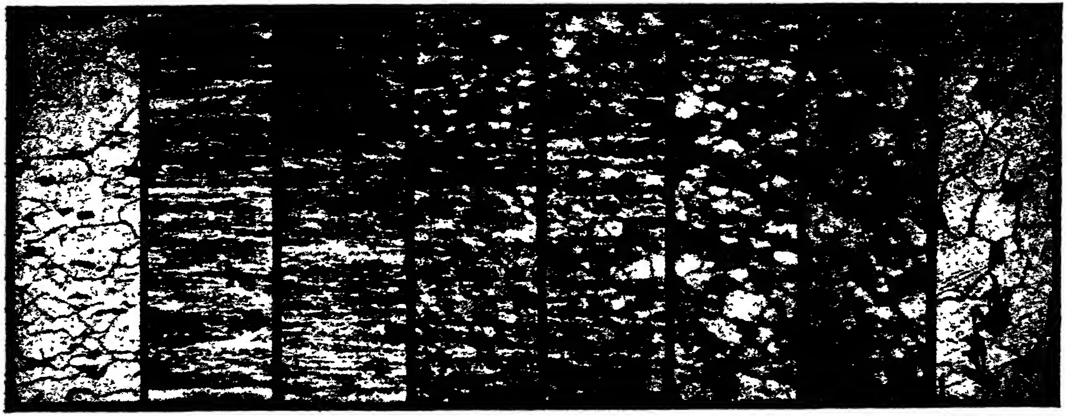
has been chosen. The wire was drawn at a tensile strength of 64·43 tons per square inch, it was then heated up to the temperatures as shown in the above table.

For the purpose of illustrating the changes that take place in the steel a composite photograph, Fig. 131, has been prepared ; both this and Figs 132 and 133 being to a magnification of 100 diameters. The section at the left of the photo shows the structure of the rod just before it was drawn. No. 1 shows the structure of the same steel when drawn down to the 16 gauge wire. Then Nos. 2 to 7 show the varying structures of the wire when heated up to the corresponding temperature shown in the table. It will be seen that when the wire is heated to 540° C. very little if any change has taken place in the structure. Then, when heated to 600° C., photo No. 3 shows that crystals have commenced to develop and the drawing lines are gradually disappearing. At 840° the drawing lines have almost gone, and the wire has completely changed into the crystalline form. At a little higher temperature than this, for annealing purposes, the steel attains its softest condition. At 900° the structure is very little altered to that which obtained at the next lowest temperature, but when the wire is heated up to about 1,000° then the structure completely changes, as is shown by No. 7, the crystals now becoming very large, the structure of the steel being practically brought back to the same condition as when in the rod before drawing.

The small black areas shown on the rod structure, and also again on No. 7, are the parts of the steel which contain the carbon.

Having now dealt with the changes that take place in steel which has been heated up and then very slowly cooled, we will next deal with a steel which is heated up to certain temperatures and then quenched in water.

It is generally thought that when mild steel is heated and quenched in cold water that its physical properties



Rod. 1 2 3 4 5 6 7

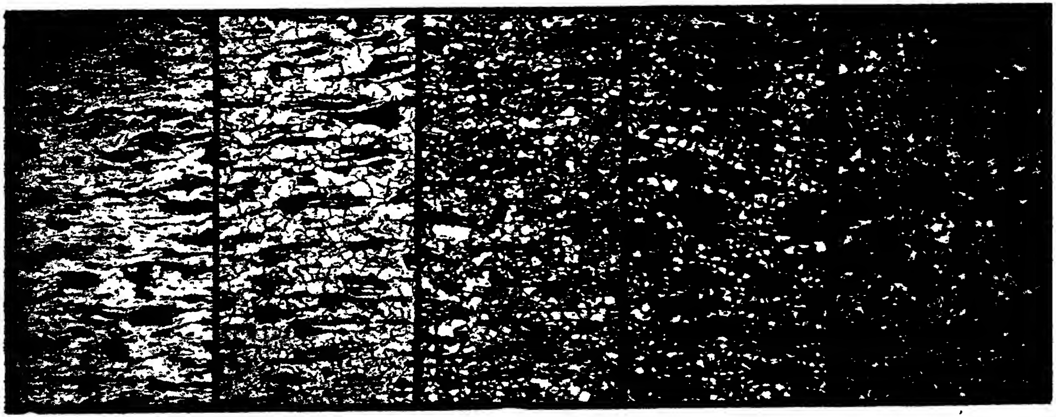
FIG. 131

alter very little, but, whilst this may be true of fairly large masses, it certainly is not true of thin wire or small sections.

For the purpose of carrying out a heating and quenching experiment a piece of 13 gauge wire was used, having a carbon content of ·20. Various heating and quenching tests were made, the results being as follows—

No. of Test.	Treatment.	Tensile Strength.
1	Wire 13 gauge	53·25
2	Heated to 720° C. and quenched . .	34·00
3	„ „ 740 „ „ . . .	44·70
4	„ „ 785 „ „ . . .	61·50
5	„ „ 810 „ „ . . .	73·10
6	„ „ 850 „ „ . . .	90·90
	Cooled from 850° C. and	
7	Quenched at 800	72·20
8	„ „ 750	63·00
9	„ „ 705	50·25
10	„ „ 640	30·80

The corresponding micro-photos are shown in Figs. 132 and 133. No. 1 photo (Fig. 132) shows the structure of the 13 gauge wire as drawn, this giving a tensile strength of 53·25 tons to the square inch. When the wire is heated to 720° C. and quenched, it will be noticed that its tensile strength falls to 34 tons to the square inch, this representing the minimum strength of the wire under quenching conditions. In photo No. 2 it will be seen that a slight crystal growth is taking place in the white areas, these latter being practically pure iron; the black areas it might be mentioned being that part of the steel which contains the carbon. When the wire is heated to 740° C. and quenched, the tensile strength has gone up to 44·7 tons, the corresponding structure in No. 3 now being of



1 2 3 4 5

FIG. 132

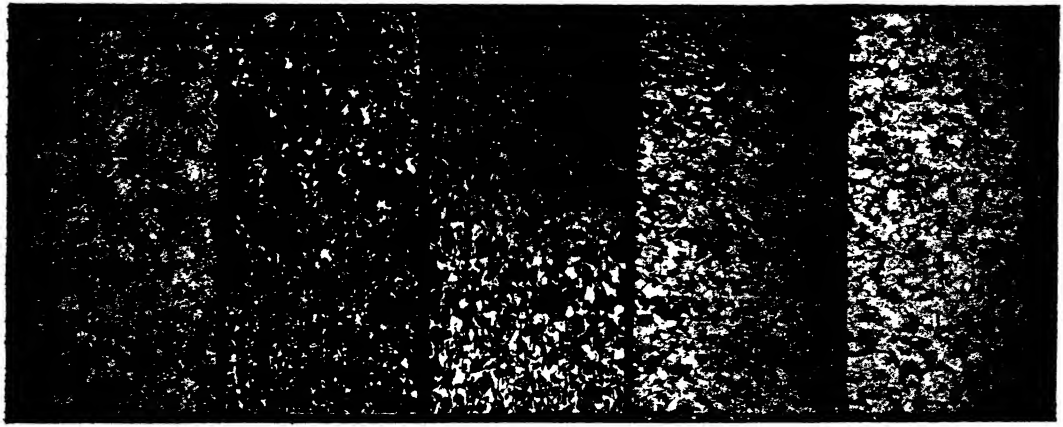
a more refined nature than No. 2. With increase of temperature it will be noticed that the tensile strength rapidly rises. When the quenching temperature is 850° C. the tensile strength has increased to over 90 tons per square inch.

No. 6 photo (Fig. 133) shows the structure at this high temperature, this being what is known as martensitic in character. In this condition all the carbon has completely gone into solution, there being no free black areas of pearlite, which contain the carbon, or free white areas of ferrite, which is practically pure iron.

The photos 7 to 10 show the structure of the steel, which has been treated a little differently. In each of these cases the wire has been heated up to 850° C. and then allowed to cool to certain definite temperatures before quenching. Thus, in No. 7, the wire was heated to 850° C., allowed to cool to 800° C., and then quenched. In this instance it will be observed that the tensile strength was 77·2 tons per square inch, showing a drop of about 13 tons from No. 6. Comparing photos No. 6 and 7 it will be seen that in the latter case small white areas of ferrite are reappearing.

In No. 8 where the wire has been allowed to cool to 750° C. before quenching, the tensile strength has fallen to 63 tons per square inch, and in the micro-photo it will be seen that the white areas have considerably increased, and that definite dark areas are commencing to form. In No. 9 with a lower cooling temperature, it is seen that the black and white areas have become more clearly defined, and that in this case the tensile strength of the wire has fallen to 50·25 tons per square inch.

In No. 10, where the wire has been allowed to cool down to 640° C. before quenching, the structure is very much the same as that of the rod from which the wire has been drawn, except that it is of a rather more refined nature. In this case it will be noticed that the tensile



6 7 8 9 10

FIG. 133

strength has fallen to 30·8 tons per square inch, or a drop of practically 20 tons from No. 9, simply by allowing the wire to cool down 65° C. lower before quenching.

The above experiments show what an extraordinary range of physical properties, with corresponding micro-structure, it is possible to obtain in even one kind of steel by variations of heat treatment.

A careful examination of Figs. 132 and 133 will show that in photos 2 to 4 the drawing strains or lines are gradually being removed, and on examining photos from 5 to 10 it will be seen that the drawing lines are not only completely removed, but that they never reappear.

Too much importance cannot be attached to the micro-structure of metals, as from what has already been said, any change in the physical condition of the steel shows some corresponding change in the structure of the material.

Many failures in metals can be attributed to the micro-structure not being of the right character, either through want of uniformity in the metal, or through wrong heat treatment, and what is sometimes described as a machine or engine failure is often due to a defective metallic structure.

The Effect of Heat and Cold on Hard Steel. The group of micro-photographs, all to a magnification of 100 diameters, Figs. 134 to 138, have been very carefully prepared to show the different structures which are set up under varying conditions of heating and cooling in a piece of ·55 per cent carbon steel.

Fig. 134 of the group shows the characteristic structure of a piece of untempered rod as it comes from the rolling mills. In the micro-photograph it will be noticed that there is a distinct white network, and in the meshes of the network dark islands. The white network is practically pure iron and is called "ferrite"; the enclosed dark areas which contain all the carbon is called "pearlite." It will be remembered that this constituent always contains ·89 per cent carbon.

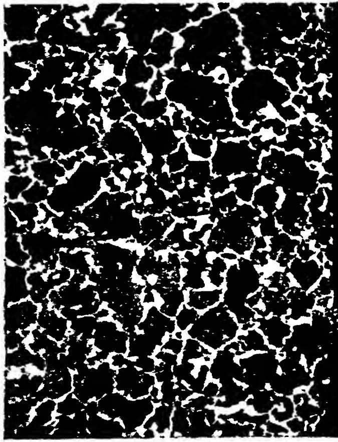


FIG. 134 FIG. 135 FIG. 136

A piece of ·55 per cent carbon steel was taken, heated to 900° C. and immediately quenched in cold water. After being polished and etched in the same way as the untempered rod, a micro-photo was taken and this has been reproduced in Fig. 135 in the group. It will be observed that the structure is entirely different to that of Fig. 134, and what is true of the structure is also true of the physical properties of the steel. It has now become extremely hard and brittle, being about 200 times as hard as soft iron. It should be distinctly understood that the structure portrayed is that which obtains in the steel when it was red-hot, the result of the quick quenching being simply to "fix" this structure as a photographic image is fixed in the developing processes of photography.

It will be interesting to follow the changes that have taken place in the untempered rod as it was heated from atmospheric temperature right up to the 900° C. above mentioned. As soon as it arrived at a low red heat the black "pearlite" areas commenced to be absorbed, this change being shown in Fig. 138 of the group. As the temperature is increased a little higher, more of the dark areas are absorbed, and thus disappear as shown in Fig. 137, but both in Fig. 137 and Fig. 138 it will be observed that the ferrite network is still intact. After a few more seconds of heating the whole of the dark areas disappear, and also some of the ferrite network, it will be noticed, is commencing to be dissolved. This state is shown in Fig. 136 of the group. After the lapse of a few more seconds the whole of the ferrite network is entirely absorbed and we arrive at the state as shown by the micro-photo, Fig. 135. This hard condition of the steel is what is called "martensite," the term being coined after a well-known metallurgist of the name of Maartens.

In this martensitic condition of the steel, the whole of the constituent parts are in complete solution. Perhaps the term "solid solution" ought to be used, for it is

evident that all the changes take place whilst the steel is in a solid state This, it is true, is an extraordinary phenomenon, but, nevertheless, the fact remains that the different constituents of solid metals are dissolved or thrown out of solution in somewhat the same manner as sugar or salt is in water under changes of temperature. Before passing on it might be as well to explain that this

FIG. 137

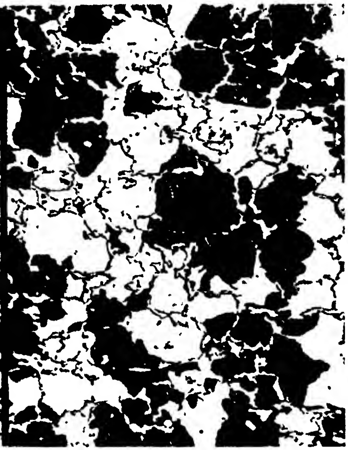


FIG. 138

hard structure of martensite is shown in all the microphotos reading from Fig. 138 to Fig. 135. In Fig. 138 the martensitic form is shown by the large white areas which have taken the place of some of the black areas seen in Fig. 134, and then in Fig. 137 it will be noticed that the whole of the groundwork with the exception of one or two black patches and the ferrite network, is of this constituent. In Fig. 136 the proportion of martensite has grown enormously, all the pearlite having disappeared and only fragments of the ferrite network being left. In Fig. 135,

as previously mentioned, both the pearlite and the ferrite have been completely dissolved, the whole of the area now shown being that of the hard constituent, martensite.

Having dealt with the transformation which takes place in steel when it is heated up to about 900° C. it will be as well to explain the alterations that happen in the structure as the steel is cooled in various ways. If a piece of this same ·55 per cent carbon steel rod be heated up to about 900° C. and then allowed to cool down very slowly, it will come back almost to the original structure as shown in Fig. 134, the only exception being that the grains or crystals will be somewhat larger. The increase in the size of the crystals depends upon the temperature and the length of time the steel is heated; it would, therefore, really mean that in cooling down from a good red heat there has been a complete change of the structure following in the orders of Figs. 135, 136, 137, and 138, and then the final change being from the structure shown in Fig. 138 to that back again to Fig. 134. What has already been said with regard to the growth of crystals, can be seen on the micro-photographs, Fig. 138, if the black pearlite areas and the white ferrite network on this be compared with Fig. 134.

It should not be forgotten that the whole of the above changes take place over a short space of time, being generally somewhere about 30 seconds. Now in slowly cooling down a piece of this steel, with very careful manipulation it is possible to quench it out in cold water during any instant of the 30 seconds over which the change is taking place, and if this is done all kinds of intermediate structures can be obtained showing just what is happening in the steel at that particular instant. For instance, the structure as shown in micro-photo, Fig. 136, was obtained by allowing a heated specimen to cool down to 720° C. and then quenched out, thus showing how the structure has altered from 900° C., as shown in Fig. 135, to that in

Fig. 136 at the lower temperature. If, however, the specimen be allowed to cool down to 690° C. and then suddenly quenched, it will be observed, as shown in micro-photograph, Fig. 137, that the ferrite network has completely formed and that some of the pearlite, shown by the small black patches, has commenced to develop.

Now when a piece of steel after cooling arrives at a temperature of 690° C. some extraordinary change takes place in the molecular condition of the material, for here not only does cooling cease for an instant, but an actual increase of temperature on the surface takes place, and brings about what is known as a "recalescence" effect, which means that through some peculiar inter-action heat has been released and the outer part of the steel heated up. This effect can be observed at any moment in watching rods or wire coming from a tempering furnace, for at a particular instant when the wire is cooling down, it will be seen to suddenly heat up again and then gradually cool off. During this, what we might call giving out of heat period, great changes are taking place in the steel and this can be best seen by careful examination of the micro-photograph, Fig. 138. This was quenched off at the same temperature as Fig. 137, viz., 690° C., but at a slightly later time during the transformation period, and shows perhaps better than any other way what is actually taking place in the innermost parts of the steel. In Fig. 137 the black pearlite areas have commenced to grow and at a little later stage in the transformation, although at the same temperature, the micro-photo, Fig. 138, shows that the black areas are growing very rapidly, this taking place in an interval of time of only a few seconds. In a few more seconds the whole of the white areas of martensite will have disappeared, these being completely changed into blank areas, and thus the steel comes back to its original form.

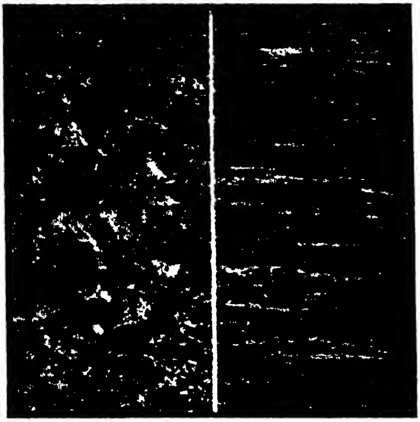
The changes that take place in a piece of steel as it

cools down from a red heat are exactly the same as those which happen in heating the metal, only in the reverse direction, and also there is just a little difference in the temperature at which the changes occur.

Tempering or Patenting. It has been mentioned that the time of transformation for a piece of steel is about 30 seconds, this time depending upon the amount of other elements or impurity in the steel.

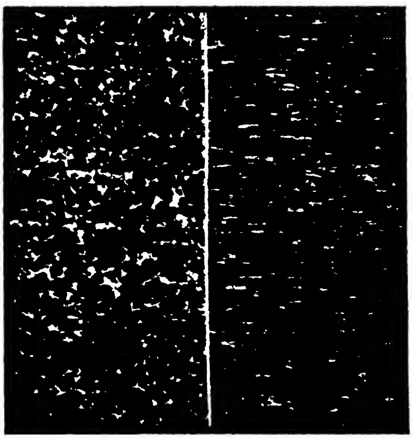
Now it might readily be conceived that if this natural time of transformation can be altered then quite different structures can be obtained in the metal, and this in practice is what really happens in the process of what we call "patenting," which means that by suitable heat treatment we engender in the steel certain properties of hardness combined with toughness which the material does not possess naturally. Thus, if the time over which the transformation takes place is reduced from 30 to about 15 seconds, there is what might be called a damping down of the changes, and we obtain a resulting structure as shown by No. 1 micro-photo in Fig. 139, to a magnification of 150 diameters. This structure, it will be seen, is quite different to any of those shown in Figs. 134 to 138, and has been given the name of "sorbite" after Dr. Sorby, who was one of the very earliest workers with the microscope on metals. On examining the photo it will be observed that the structure is very indefinite, showing that there has been a retarding of the changes whilst the transformation is taking place. It has been found that this type of structure gives a maximum strength combined with toughness, and thus gives the best physical properties for the requirements of steel wire or other product. To obtain this structure is no easy matter and requires very great care in the manipulation of any plant or furnace that is attempting to produce same.

The method by which a tempered structure is obtained by quickening up the method of cooling, may be called



1 2

Fig. 139



1 2

Fig. 140

"positive tempering" as compared with what may be described as "negative tempering" or "letting down," this latter method taking the form of re-heating a piece of steel to a certain definite temperature after it has been quenched out in water or other cooling liquid, and thus reducing its hardness and increasing its toughness.

For the sake of comparison micro-photo No. 2, Fig. 139, shows the type of structure obtained after sorbitic steel (No. 1, Fig. 139) has been drawn into wire, this steel being of ·69 per cent carbon.

To show the difference between tempered and untempered rod, Fig. 140 gives two micro-photographs, No. 1 of the untempered rod, and No 2 of the untempered rod drawn into wire, of the same carbon steel as shown by the photos on Fig. 139. A careful comparison of these two pairs of photographs will show that although the carbon content is exactly the same in both cases, the resulting structures are entirely different, and it hardly need be stated that the resulting wires will have entirely different properties.

CHAPTER XVIII

WROUGHT IRON AND CAST IRON

IN the last chapter it was explained that mild steel is composed of about 99½ per cent of iron, together with about a half of 1 per cent of other constituents. The question that now readily comes to one's mind is "What is iron?" Here Nature slams the front door of her house in our face and leaves us outside until such times as we are able to bring a key which will unlock the door and let us into the secret places of her dwelling.

There is no doubt whatever that the real answer to our question will come in the no distant future, when the greater depths of the mysteries of matter have been more fully explored. For the present, however, we must be content with the knowledge that iron is spoken of as a simple or elementary substance that is just composed of itself and nothing else. Up to the present time, some eighty elements of different kinds of matter have been discovered in Nature, of which about sixty-four are metals and the remainder non-metals. Some of the simple metals are copper, gold, zinc, tin, lead, iron, and sodium; and a few of the non-metallic substances are sulphur, carbon, oxygen, hydrogen, and chlorine. Now, of the twelve substances named, nobody has yet succeeded in dividing up either of them into any other kind of matter, hence they are called "elements." A compound substance is composed of two or more elements, thus, to give an illustration, common salt consists of sodium (a metal) and chlorine (a gas), these two being found in Nature combined together in the definite weights of 23 parts of sodium to 25½ parts of chlorine. Water is another compound, formed of eight parts of oxygen to one part of hydrogen, both of these

elements in their ordinary state being gases. It should be noticed that compounds have altogether different properties from those of the elements of which they are formed. Thus chlorine, a virulent poison (which was extensively used during the last war as a poison gas) when combined with the metal sodium becomes inert, and as common salt can, of course, be used beneficially. Very few of the elements exist naturally in their simple form, and that is the reason why it has been so difficult to discover some of the more uncommon kind.

Iron exists in great quantities, and is very widely spread over the earth's surface, yet it is very rarely met with in its native state, and even then only in microscopic quantities. It is usually found combined with oxygen, carbon, sulphur, etc., and as iron-ore bears very little resemblance to pure iron, it is not always easy to detect the presence of this element in a substance. Iron-ore may have a great variety of colours, being either white, brown, yellow, red, and almost any shade of these, depending upon its composition. Many of the colours in earthy matter, clay, etc., are due to the presence of iron, in fact, the common red brick owes its colour very largely to the presence of iron oxide.

Some of the best specimens of native iron have been found in connection with meteorites—those strange wanderers in space, which, as shooting stars, we occasionally observe making a dive towards the earth.

The difference between wrought iron and mild steel is very marked, the former due to its method of manufacture being fibrous, whilst the latter is not so. The composition of the two vary very little, yet there is a considerable difference in their properties, indeed, the term "mild steel" is more or less a misnomer, and it has been proposed that "ingot iron" should be substituted for this, so as to avoid any confusion in the use of the term "steel." In the manufacturing of wrought iron, the pig iron in the furnace is really never brought to a molten state, but is

simply puddled in a pasty form for the removal of a fair proportion of its impurities. The puddled ball or bloom is then removed to be hammered and rolled. In this process further impurities are squeezed out, and those remaining take up the form of slag threads, which are made longer and thinner by rolling and drawing. The

FIG. 141

structure of a piece of wrought iron bar is shown in Fig. 141, to a magnification of 100 diameters. Here two large slag threads are seen running lengthways of the bar, and there are also numbers of small slag threads; in between these will be observed the crystals of iron. It should be noticed that these alternate threads or layers of slag and iron give wrought iron its distinctive property of being fibrous. Indeed, this is one of the ways by which wrought iron can be quickly tested in a practical manner, as shown by Fig. 142.

In the earlier days, up to about two centuries ago, the

iron-worker nearly always made his own iron before proceeding to work it up into either wire or any other shape. This he did fairly simply by mixing iron-ore and charcoal together and heating until he obtained a pasty mass, which he proceeded to hammer out to form a little lump of crude iron, then by continual hammering (hence the

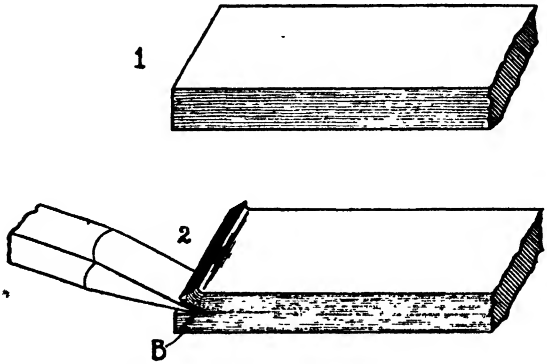


FIG. 142.—IRON SLAG THREADS. PRACTICAL TEST FOR IRON.

(1) Exaggerated slag threads in laminations.
(2) Parting the laminations at the point *B* by applying a chisel and forcing them apart. At this point *B* after the separation will be seen the dark coloured streaks of the slag, which does not exist in mild steel.

name " wrought iron ") he gradually improved the quality of the metal. This has given rise to the common idea, which is quite correct, that wrought iron is considerably improved when well hammered at the proper temperature.

The structure of a piece of iron made by one of the old workers of two and a half centuries past is shown, to a magnification of 100 diameters, in Fig. 143, this being taken from an old horse-shoe nail of an early period. In this specimen it will be noticed from the structure on the microscopic photograph that the slag threads are finer than in Fig. 141, showing that the material has been well worked. The specimen of metal from which this was taken

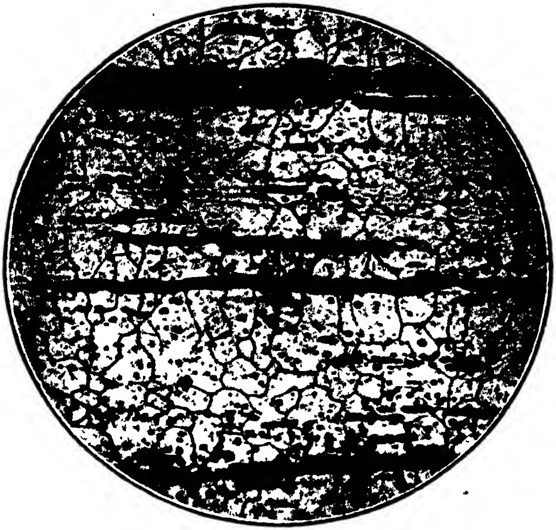


FIG. 143

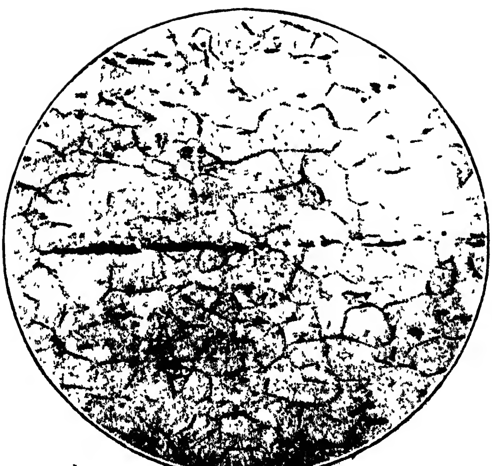


FIG. 144

was simply polished and not etched as with Fig. 141, and this accounts for the fact that the crystals in between the layers do not show up as in the first photo.

The good quality of Swedish charcoal iron has been extolled for many, many years. This fine quality is due to the great purity of the material, and this is seen in the structure of a charcoal rod, as shown by the microscopical photo (Fig. 144). It will be noticed that the threads or patches of slag are very few and very small as compared with the structures shown on Figs. 141 and 143. Also in Fig. 144 the beautiful crystal formation will be observed, which is always characteristic of a pure iron. The crystal grains here are rather large, but even these amount to about 12,000 to the square inch. In the specimen shown, the weight of total impurities only amounts to about $\frac{3}{4}$ oz. in 100 lbs. of the metal. In spite of all that has been said about charcoal iron, one of its defects is want of uniformity in composition. It may also be mentioned that some kinds of mild steel are practically as good in quality as charcoal iron.

The great value which is attached to iron is due to the fact of its plentiful supply, there being only one other metal, namely, aluminium, of which there is a greater quantity on the earth's surface. It is easily produced from its ores, and consequently can be sold at a comparatively low price. Its chief virtue is in its enormous strength, a bar of wrought iron, one square inch in section, requiring no less a pull than about 20 tons before it can be broken. Roughly, this means that if a bar of iron, one inch square, was used instead of a rope in a tug-of-war, the pulls of about 300 men on each half of it would be required to break it asunder. By the addition of suitable materials to form steel, together with subsequent treatment, like wiredrawing, this strength of 20 tons can be increased up to as much as 250 tons. Also, its properties of ductility and malleability are exceedingly valuable, as through

these iron can be worked into an infinite variety of shapes and forms.

Whilst iron has all the advantages mentioned above, it has one very serious disadvantage, and that is the readiness with which it corrodes and wastes in a damp atmosphere. Here is a fruitful field of investigation for the young inventor, as vast fortunes await the man who can find out a method of making up iron so that it shall be non-corrosive. Some progress has been made in this direction by the invention of rust-nor-stain cutlery steel and acid-resisting cast iron, but these methods of treatment are unsuitable or too costly for application to ordinary iron or steel work.

The use of iron has become so interwoven with our very existence, that it is difficult to conceive what the world would be like if this wonderful metal was banished from our midst.

A simple workshop test to tell the difference between wrought iron and mild steel is to nick and bend the bar to see if it is fibrous or a test may be carried out as shown on Fig. 142.

Cast Iron. Seeing that cast iron is the basis of all the "iron" materials we use, either in the form of mild steel or hard steel rods, bars, etc., tools, machines, benches, and so on, it should be of interest to all classes of workers to know something about this very important material.

The discovery and uses of cast iron really belong to what one might term the second period of the growth and development of the iron industry. The first period began in the earliest days of mankind, and covered the making and uses of wrought iron in its very crudest form. The second period began in the fourteenth century, when cast iron came into use, and what may be called the third period was ushered in when Bessemer invented his process, about the year 1855.

There is no doubt whatever that cast iron had been

accidentally made hundreds of times by the early iron-workers in their small primitive furnaces, but this would be looked upon as spoiled iron, and would be thrown away. This is indicated by the great number of pieces of crude cast iron which have been discovered amongst cinders in the various districts where iron had been made, and which have subsequently been used up. It is quite possible also that some of the earliest weapons of warfare which have been found to contain steel, were manufactured by a combination of some of this accidentally made cast iron being mixed up with the plastic wrought iron, and so getting the necessary carbon to convert it into steel.

Essentially, the difference between cast iron and wrought iron is in the percentage amount of the constituents which are found respectively mixed with iron in the two cases. Typical comparative analyses are as follows—

	Cast Iron.	Wrought Iron.
Carbon	3·5	·08
Silicon	1·75	Trace
Sulphur	·12	·03
Phosphorus	1·2	·02
Manganese	·60	·15
Iron	92·83	99·72
	100·00	100·00

It will be seen that the cast iron has about 7 per cent impurities, against about ·30 per cent in the sample of high quality wrought iron. There is also a big difference in the melting point, wrought iron fusing at about 1500° C., whilst the cast iron will melt at a temperature of about 1150° C.

Modern microscopy also gives very clear indication of the difference between the structure of wrought iron or

mild steel and cast iron. This is clearly shown on comparing Fig. 127, which gives the structure of a sample of best mild steel rod, with that of Fig. 145, which shows the structure of a specimen of white cast iron. It will be seen that these structures are entirely different, bearing very little relation to each other.

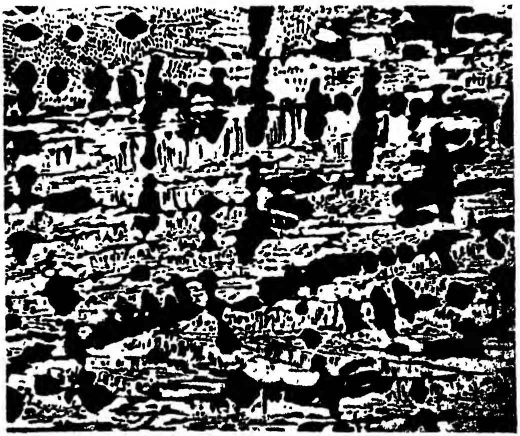


FIG. 145.—WHITE CAST IRON

The micro-structures of cast iron show that the constituents are not intimately mixed, but form their own particular compounds according to the percentage amount of impurities they contain, the method of cooling, etc.

The structure shown on micro-photograph, Fig. 145, is that of a quickly cooled cast iron. In this the constituents have not had time to completely separate out, hence, giving the characteristic appearance of white or "chilled" iron. It will be noticed that there are two distinct areas, one white, the other black. The white areas denote the hard or chilled portion of the cast iron, which has been named "cementite," this being a chemical compound

composed of iron and carbon. This part of the cast iron contains about 6 per cent of carbon. The dark areas have the same composition as the small black areas shown on the mild steel micro-photograph, these being of what is called pearlite formation. It will, perhaps, be as well to mention that the pearlite parts of the cast iron contain

FIG. 146.—GREY CAST IRON

about ·9 per cent of carbon. Hence it will be noticed that in this kind of cast iron there are adjoining parts, one respectively containing about eight times the amount of carbon of the other.

In white cast iron practically the whole of the carbon is in combination with the iron, but in grey cast iron, due to the slower cooling, the carbon is thrown out of solution and is seen in the iron in the form of graphite flakes. A typical structure of this kind of cast iron is shown in Fig. 146, where from the analysis it will be seen that about four-fifths of the carbon is thrown out as graphite. On

FIG. 147.—PHOSPHIDE OF IRON IN GREY CASTING

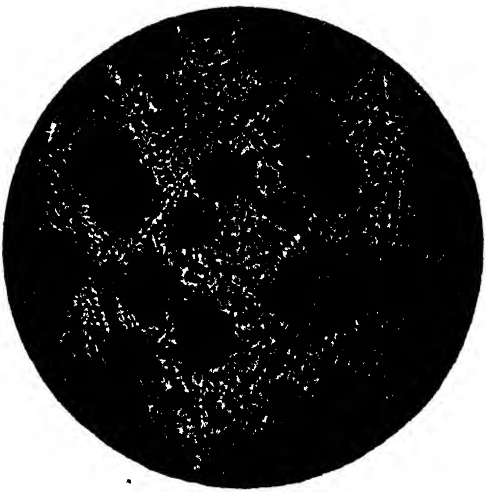


FIG. 148.—MOTTLED CAST IRON

the micro-photograph the graphite is shown as long black streaks bounded with white borders. The white border areas are the parts that contain very little carbon, showing that in the slow cooling this element has gradually passed out to form the graphite flakes as seen. Careful examination of the photograph will also show two other areas, one being dark and the other grey, but for purposes of examination a micro-photograph to a much higher magnification (460 diameters) of these areas is shown in Fig 147. The areas marked *P* show the pearlitic formation, which it will be observed is of a laminated character, the black lines representing plates of pure iron, the white areas in between being formed of the hard substance cementite. The phosphorus in the cast iron goes into combination with some of the iron and forms its own particular grey structure; this on Fig 147 is denoted by the three X's, as a network surrounding a small "island" of pearlite.

In passing, it might be mentioned that the structure of pearlite can only be seen, as in this case, under a very high magnification.

Mottled cast iron is a material which lies intermediate between the white and grey varieties. As will be seen from Fig. 148, the structure is of a more refined character than either of the other two. The amount of combined carbon, it will be observed, is greater than in the grey cast iron, and less than the white iron. There is free graphite as with the grey iron, but this is in a much more finely divided state than in the latter. The dark "island" areas on the micro-photograph show pearlitic formation, whilst the light areas show a very fine network of cementite. Interlaced with this latter there also runs a greyish network containing the phosphorus.

Without going into further detail, sufficient has been said to give some indication as to the difference between mild steel and the various classes of cast iron.

CHAPTER XIX

COPPER AND ALUMINIUM

'er. This metal appears to have been known from ne very earliest times, and seems to have been used both or domestic and decorative purposes, and also, when alloyed with tin, for the making of edged tools and nstruments of war.

The early Romans were evidently well acquainted with the use of this metal, for several Roman medals have been found of about 500 B.C. having a composition of about 70 per cent copper, 22 per cent lead, 7·5 per cent tin, and ·5 per cent iron. A medal of the period of Alexander the Great, 335 B.C., was found to contain about 87 per cent copper and 13 per cent tin. A camp kettle of the same period was composed of 88 per cent copper, 6 per cent tin, and 6 per cent lead. A brass article of 20 B.C. was found on analysis to give 81 per cent copper and 17 per cent zinc, together with a little iron. This is rather peculiar, as zinc was not supposed to have been discovered until more modern times, but the explanation is that the natives used the ores of zinc to mix with copper without knowing anything of the metal zinc itself.

The ancient inhabitants of Peru, the Incas, were no doubt well acquainted with the use of copper, as Humboldt, the early explorer, brought away from Peru a chisel which was composed of 94 per cent copper and 6 per cent tin, and also a knife of 96 parts copper to 4 parts tin. It is rather interesting that both the early Mexicans, the Aztecs, and the Peruvians seem to have been quite unacquainted with the use of iron, although the ores of this metal were o be found in each country, but both peoples were onsiderable workers in copper, silver, and gold.

It is on record that a copper mine was worked in the very early days of the Egyptians.

It is impossible to say when the metal was first used, but it is quite probable that it came into use when native copper was originally discovered. Subsequently there is no doubt that the process of obtaining the metal must have been exceedingly laborious and tedious, beyond the conception of those now engaged in extracting the metal from its ores.

There are records which show that both the Syrians and Phoenicians were large traders in copper and tin, and during their search for the latter metal in Great Britain and Ireland no doubt found considerable quantities of copper. Several bronze articles have been found in the old workings in Cornwall which can be attributed to these people.

Copper is found as the pure metal in but few districts. Some has been found in the mines of Cornwall, some also in Brazil and Siberia, but the greatest finds have been in the Lake Superior district of America, where it occurs in large quantities and has been in use from very early times. It was, therefore, the first metal to be utilized for practical purposes by the natives of these regions.

In the Lake Superior district it has been found in huge masses, some of these weighing many tons. One of these great lumps of metal is illustrated by Fig. 149, this, which is of many tons weight, having been found in one of the old workings, together with numerous stone hammers. It had been pounded and cut with these tools until every projecting part had been broken away, hence the whole surface has the appearance of being well hacked. Many axes, war weapons and other objects of days long past, all fashioned from the native copper by simple hammering, have been dug up from time to time.

It is interesting to note that the natives of these districts never seem to have discovered the art of melting the metal and casting it into moulds, so that although acquainted

with metal they still remained in something like the Stone Age of culture.

A good deal has been said about the wonderful skill which some of the metal workers of the Bronze Age possessed in the manipulation of the metal copper so as to make it sufficiently hard for edged cutting tools. But

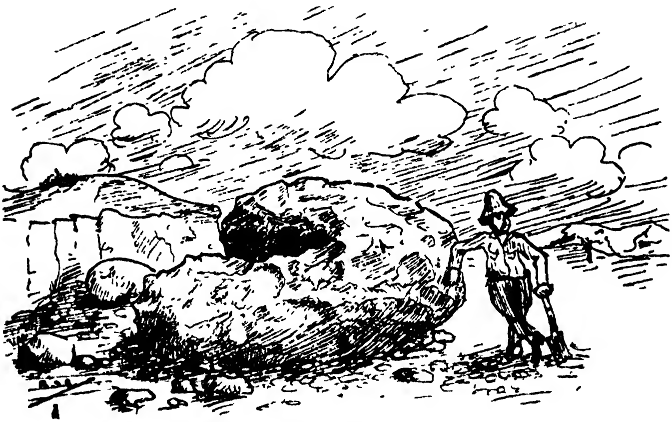


FIG. 149

examination of hundreds of early weapons and implements shows that there was nothing of a very definite character about these, most of them being composed of a bronze which contained copper with from 3 to 18 per cent of tin. Then it has also been stated by some that they possessed a method of obtaining great hardness for the cutting edges of their weapons by some method of tempering, but this is extremely doubtful as examination shows that the actual hardness obtained was simply produced by intense hammering of the cast bronze.

Copper has a strong red colour, is very malleable, ductile, and tenacious. The strength of the metal, however, in the cast state is only about half that of iron, but when

rolled or drawn the strength rapidly increases, and when alloyed with other metals it can be made almost as strong as steel. It is a little heavier than iron, a piece of copper of the same size as a piece of iron being about one-seventh heavier. The metal is, of course, a much better heat and electricity conductor than iron. It has a fairly high melting point, this being 1065° Centigrade. Under ordinary conditions it offers considerable resistance to corrosion, and for this reason in the Middle Ages was used for the roof coverings of houses and important buildings, and, indeed, is sometimes used now for the same purpose, particularly for churches. Although it offers considerable resistance to ordinary atmospheric corrosion, the metal is readily absorbed by vegetable and meat juices, and for this reason should not be used in the bare state for domestic utensils.

Iron and steel is readily coated with the metal by dipping into a solution of sulphate of copper. Unfortunately, this copper coating offers very little resistance to the corrosion of the iron on account of the latter metal being electro-positive to the former, the two metals being in contact actually accelerating the wasting away of the iron.

Copper, like pure iron, when it solidifies from the molten state, forms crystal grains, as will be seen on Fig. 150, this micro-photograph being to a magnification of 100 diameters; the surface of the metal before being photographed was carefully polished and etched with suitable acid to bring up the boundaries of the crystal grains. The small dark specks shown in the grains are oxide of copper, a compound which is readily dissolved by molten copper and considerably affects its properties, a small percentage making the metal quite brittle and unsuitable for use.

During the last few years it has been found that copper can be readily welded by the aid of the oxy-acetylene blow-pipe, the metal being simply fused and a copper wire containing a small amount of phosphorus run into

the joint. A micro-photograph of a weld in copper is shown in Fig. 151. Through being heated to a high temperature the grains have grown very large, and although this photo is to the same magnification as Fig. 150, it is not large enough to contain one single grain. The line *CBA* is one boundary of a large grain, part of which

Fig. 150

is shown on the upper side of the line. The same is also true of the grain *CBDF* and the grains *ABDE* and *EDF*. The peculiar line markings in each grain are due to the metal having been strained under testing, and so causing one grain to slip through the other.

Copper is considerably hardened when small portions of other metals are added to it. A good illustration of this is the copper coinage, which is composed of 95 parts of copper, 4 parts of tin, and 1 part of zinc.

When copper is alloyed with zinc it is usually called brass, although brasses sometimes contain small portions of other metals in addition.

When copper is alloyed with tin it is usually called bronze, but the subject of mixed metals is an exceedingly important one and merits a chapter of its own.

FIG 151

Aluminium. Aluminium is one of the most widely distributed elements in Nature, and of all the metals it is the one of which there is more in the earth's crust than any of the others, there being 7·8 per cent of aluminium in the earth as compared with 5·4 per cent of iron. It will thus be seen that there is about one and half times as much aluminium in the earth's crust as there is of iron. This is a somewhat extraordinary fact when one remembers that aluminium was not discovered until about 90 years ago,

and not used very much commercially until the last 30 or 40 years.

It is not difficult to understand why aluminium was not discovered earlier when it is taken into account that it is never found in Nature in its native state, and also that it is not an easy metal to extract from its ores.

It cannot be stated with any certitude who first discovered aluminium, but it is on record that Davy unsuccessfully attempted to reduce the metal from its oxide in 1807. Oersted, in 1824, managed to produce a metal which, it is pretty certain, was aluminium. There can be no doubt that Wohler, in 1827, made small quantities of the metal, and Bunsen and Deville, in 1854, extracted the metal from its ores by means of electrolysis. Since the last date mentioned many developments have taken place in the production of aluminium, and at the present time the metal is manufactured on a fairly large scale by the British Aluminium Co.

In Nature it is found as one of the important elements in corundum, emery, alundum, and in many precious stones, such as the ruby, sapphire, topaz, etc., and it is also found in the various clays. Its chief ores are bauxite and cryolite, the former being oxide of aluminium together with some iron oxide and silicon, the latter being a compound of aluminium and sodium fluoride. Under present methods of manufacture aluminium is obtained with a purity of 99 per cent to 99½ per cent, its chief impurities being silicon and iron.

It has a specific gravity or relative weight of 2·7, which shows that it is about one-third the weight of iron when equal volumes are taken. Its melting point is 657° C. It has a tensile strength in the cast state of about 7 tons to the square inch, which may be increased up to as much as 15 tons when the metal is rolled into a sheet, and when drawn down to fine wire its strength can be increased up to about 29 tons to the square inch.

On account of its great malleability it can be rolled down into very thin sheets, the metal foil being about $\frac{1}{40,000}$ of an inch in thickness. It is an extremely good conductor of heat and electricity, and has the distinction of absorbing more heat to raise it up to a given temperature than most of the ordinary metals.

It has a great affinity for oxygen, which is one of the reasons for the difficulties found in either soldering or welding the metal.

When exposed to a dry atmosphere the polished metal keeps fairly bright, but when exposed to a damp atmosphere corrodes rather rapidly, which causes the metal to become rather brittle. It is also affected by being coated with any form of lead paint. Cold mineral acids attack it rather slowly, but it is readily dissolved in heated hydrochloric acid.

It is dissolved by alkalis, and this is usually one of the reasons of the metal wearing away so quickly when vessels are used for domestic purposes and cleaned with soda or dry soaps.

On account of its great affinity for oxygen it is sometimes used as a de-oxidizer in the manufacture of steel, and serves the same useful purpose when incorporated with brass wire to be used for welding the latter metal. It is also used in the making of alloys, as will be seen on consulting the table in the chapter on this subject.

The metal is also used in connection with electric welding either in the form of a fine wire attached to the electrode or as a metallic powder added to the flux, the object here again being to resist the formation of oxide of iron.

A micro-photo of an aluminium weld is shown in Fig. 112, Chapter XV.

CHAPTER XX

ALLOYS

During the last few years remarkable strides have been made in the compounding of two or more metals together to form alloys. By this means many properties have been imparted to the alloys which have not been possessed by the individual metals. From the results which have been obtained up to the present it would almost seem that the future use of metals will be very largely influenced by the way in which they are mixed with each other.

It is therefore important that the welder should have some knowledge of alloys, the metals of which they are composed, and the properties they possess. This information should act as a guide to the welder in knowing the best kind of filling material to use, and also the most suitable fluxes.

Quite a number of alloys can now be welded in most cases by the oxy-acetylene process, and to a more limited extent by the method of electric arc welding.

When a welder is called upon to weld an alloy it is a good plan to first of all find out something of its properties, and then experimentally to use a filling material as near as possible of the same composition as the alloy, along with this trying different kinds of fluxes until he finds out which one gives the best result.

Some alloys are not only very difficult to weld, but almost impossible, but a good deal of information can be obtained by the welder himself by carrying out careful experimental work.

Metals are compounded to form alloys to obtain the properties shown on p. 290.

COMPOSITION

	Aluminium.	Antimony.	Bismuth.	Cadmium.	Carbon.	Chromium.	Cobalt.	Copper.	Iron.	Lead.	Magnesium.
Acid resisting bronze .								83 05		·10	
Admiralty brass .								62			
Aich's metal . .								60	1·5		
Aluminium alloy (German airship) .	91·92							4·13	3·27		
Aluminium brass .	2·5							70			
Aluminium bronze .	10							90			
Babbitt metal (normal) . .		7						3			
Bell metal . .								80			
Britannia metal (sheet) . .		7·8						1·5			
Bronze coins—British . .								95			
Bronze bearing metal								80			
Brass (best) . .								72			
Brass (common) .								66 6			
Cartridge brass . .								64·5	35		
Chrome-tungsten steel					·7	3			83 3		
Chromium steel . .											
Chromium steel rolls .					85	·89					
Constantan . .								60			
Cronite . . .	varyi	ng pr	oport	ions	of chr	omiu	m an	d nic	kel		
Delta metal . .								55	1 0	·5	
Duralumin . .	95 5							3			·5
Duriron . . .					·3				85·11		
Fusible alloy . .			50	11						25	
German silver . .								50			
Gun metal . .								88			
Hercules bronze .	2							65			
High speed steel .					·6	4					
High tensile steel					6	·65			95 19		
Immadium bronze .											
Invar . . .					·20				63·8		
Light alloy . .	86										
Magnalium . .	94							3			2
Magnolia metal . .		15	·25							80	
Manganin . . .								82·12	·57		
Manganese bronze .								84	·5	2	
Monel metal . .								25	5		

OF ALLOYS

Manganese.	Molybdenum.	Nickel.	Phosphorus.	Silicon.	Sulphur.	Tin	Tungsten.	Vanadium.	Zinc.	REMARKS.
						10·81			6	For use with weak acid water.
						1			37	Composition varies for different purposes.
									38 5	Hard and strong.
				65						Light and strong.
									27 5	Gives good castings.
										Resists sea water corrosion.
						90				Bearing filling.
						20				For bell castings.
						90 6				Spoons, etc.
						4			1	Hard. Resists wear.
						13			7	Bearings.
									28	Very malleable.
									33 3	Soft.
									35 15	Draws well.
							13			Tools and dies.
										See Stainless Steel.
·275		·26	009	48	013					Cold rolling.
		40								High electrical resistance.
										Non-scaling at high temperatures.
									13 5	Very strong.
1										Light and strong.
·35			·2	14	04					Great acid resisting properties.
						14				Melts at a very low temperature.
		25							25	Malleable and takes good polish.
				10					2	Very tough.
									33	Strong.
·2				·1			18			For cutting tools.
										May also contain cobalt, molybdenum, and vanadium.
		3·5	03		03					For strong structural work
										Strong and acid resisting.
										Manganese bronze with a small amount of aluminium.
		36								Very low heat expansion.
				14						Sp. Gr. 2·6. Strength 13 tons per sq. in.
		1								Composition varies considerably.
						4 75				For bearings.
15·02		2·29								High electrical resistance.
1·5						8			4	Strong at high temperatures.
		67								Strong and resists corrosion.

COMPOSITION OF

	Aluminium.	Antimony.	Bismuth.	Cadmium.	Carbon.	Chromium.	Cobalt.	Copper.	Iron.	Lead.	Magnesium.
Muntz metal								60			
Mushet steel					2				88		
N. brass								66·5	1 0		
Nichrome						15			25		
Nickel chrome steel					65	75			94·7		
Nickel iron					·8				74 2		
Nicklin								68			
Non-corrosive alloys							10	80			
								50			
								20			
Pewter								1 42		1 65	
Phosphor bronze								80		10	
Pinchbeck								83 33			
Platinite					·15				52 5		
Platinoid								60			
Silicon bronze								97 12			
Silicon steel					5				97·8		
Solder										66 67	
Speculum								66 6			
Stainless steel					65	12 75					
Stainless iron					·18	12 75					
Stalloy											
Stellite					·87	10 77	59 5		3 11		
Tantiron					1				82 7		
Tobin bronze								58 1	·1		
Tubadium bronze	2							48	1	·1	
Vanadium steel											
Wiredrawing plates					1 8	13 3					
Wiredrawing plates					1 6	·1					
Wiredrawing plates					1·1	6·5					
Wood's metal			50	12 5						25	

ALLOYS—*contd.*

Manganese.	Molybdenum.	Nickel.	Phosphorus.	Silicon.	Sulphur.	Tin.	Tungsten.	Vanadium.	Zinc.	REMARKS.
									40	Rolls hot. Resists sea water.
2				1			7			Tool steel.
									32 5	Used for sheet stampings
60										High electrical resistance
		3·8	03	05	·02					High tensile steel.
		25								Air hardens. Resists corrosion.
	32									High electrical resistance
						10				Good resistance to atmospheric corrosion.
		50								
		78					2			
						97				Some pewters only lead and tin.
			·5						9 5	For acid resisting purposes.
									16 76	Imitation gold.
		46								Low coefficient of expansion.
		14					2		24	Low electrical resistance.
						1·14			1 12	High tensile strength.
·5				1·2						Spring steel.
						33·33				Common solder.
						33 3				For reflectors.
·12										For cutlery.
										For working-up purposes.
·10			·02	4·2	·03					Sheet for electrical purposes.
	22·5	2 04	·04	·77	·084					Very hard and non-corrosive.
·8			·4	15	1					High resistance to acid corrosion.
						2 3			39 5	Hard.
1·75		2				·5			46 45	For propeller castings.
	steels	with	vana	dium	not g	reater	than	·7		High elastic limit.
·13		·75								Very hard when air hardened.
·48										Soft plate.
·35										Medium hard.
						12·5				Melts at 61° C.

(1) Reduction of melting point to something lower than that of one or more of the constituent metals.

(2) Additional strength or toughness.

(3) A different colour.

(4) Resistance to atmospheric oxidation, corrosion or tarnishing.

(5) Resistance to the action of all kinds of acids.

(6) Great hardness.

(7) Better flow of metal in forming sound castings.

(8) A highly polished reflecting surface.

The composition of the commoner known alloys are tabulated as shown on pp. 286–289.

The composition of many of the alloys in the above table should not be taken as representing the exact quantities of the respective elements noted, as these vary considerably in the same alloy. The composition of some of the alloys has been determined by direct analysis, whilst others give the commonly reputed composition. Again, it should be remembered, that some metals and elements act not so much in the direction of giving peculiar physical properties to the alloys, so much as being cleansers, and in this way removing the impurities contained in some of the other metals. This is particularly true in connection with phosphor bronze where occasionally in analysing this alloy no phosphorus is found to be present. All the same, the phosphorus which was originally added to the alloy in its molten state played a very important part in deoxidizing the copper, as it does in the case of using a phosphor-copper welding rod, in this way leaving the metal very largely immune from the effects of acid or sea-water corrosion.

With regard to the term corrosion, this is only used in a relative sense, no alloy yet invented offering absolute resistance to the attack of either acids, air, or sea-water.

CHAPTER XXI

METALS AND THEIR PROPERTIES

DATA AND TABLES

THERE are altogether in Nature about eighty different kinds of metals, but on account of the unfitness of many through difficulty of extraction from their ores, rarity, or rapid oxidation when exposed to the atmosphere, the number of them in use for general manufacturing purposes is only about a dozen.

The qualities possessed by metals which enable them to be used in the various industries are—

Metallic Lustre, or the property of reflecting rays of light.

Tenacity, or the strength with which the particles of which a metal is formed resist being pulled asunder.

Hardness, the property which a metal possesses of resisting being scratched or compressed.

Malleability, the property which many metals have of being hammered or rolled out into a large surface or thin sheet without fracture.

Ductility is the property which enables a metal to be drawn into a thin wire.

Fusibility, the property which metals possess of becoming liquid when heated to a sufficiently high temperature.

Expansion and Contraction is the property which a metal has of increasing its length or volume when heated or decreasing the same when cooled. Thus, if a bar of iron 10 feet long be heated from the atmospheric temperature of 16°C. up to 750°C. its increase in length will be—

$$10 \times 12 \times 734 \times \cdot 0000119 = 1 \cdot 05 \text{ ins.}$$

The above is worked out by multiplying the rise in temperature (750-16) by the length in inches and coefficient of expansion (·0000119—taken from the following tables).

Conducting Power for Heat. The property which metals possess in varying degree for transmitting heat along or through them.

Conducting Power for Electricity. The particular quality which metals have of becoming the medium for the passage of electricity.

Specific Gravity, or relative weights of metals all compared to the weight of an equal volume of water. Thus, to give an illustration, the specific gravity of lead in the table containing the figures is given as 11·36, which means that if equal volumes of water and lead are compared, the latter will be found to be about eleven and one-third times the weight of water. Hence, to obtain the weight of a sheet or bar of any metal all that it is necessary to do is to calculate its volume, find the weight of an equal volume of water, then multiply this by the figure given in the table of specific gravity.

Specific Heat, or the relative quantities of heat absorbed by metals all compared to the heat absorbed by an equal weight of water when raised through the same temperature.

In connection with this welders should learn to appreciate the difference between the *temperature* to which a metal is raised, and the *quantity* of heat which may be absorbed by a definite weight of the metal. The temperature represents the *intensity* of the heat, but gives no indication with regard to the *quantity* of heat that may be required to raise a certain weight of metal to the indicated temperature. To understand what is meant by quantity of heat the following definition should be clearly grasped—

The British Thermal Unit (B.T.U.) is the *quantity* of heat required to raise the temperature of 1 lb. of water 1° F. at its maximum density (39·1° F.).

Examination of the table of specific heats shows that that relating to copper is about ·09. Which means to say in heating up equal weights of copper and water to the same temperature, that copper will take up about

one-eleventh of the quantity of heat that is required for the water.

In the table also it will be noticed that the figures for lead are about ·03. Comparing this with copper of ·09 it will be observed that if two equal weights of copper and lead are heated to the same temperature the copper will absorb three times the amount of heat that lead will.

In passing it is interesting to note that aluminium has a high specific heat compared to the other metals, so much so that if equal weights of aluminium and copper were heated up to the same temperature the aluminium would absorb about two and one-third times the amount of heat that the copper would: Conversely, in cooling down to even temperatures the aluminium would give out two and one-third times the amount of heat the copper would.

Latent Heat. This term is the name given to the quantities of heat that are required to convert a solid into a liquid, both being at the same temperature. For instance, when a metal is heated up to its melting point it remains at a uniform temperature until the whole of the metal passes from the solid into the liquid state. The number of units of heat, therefore, which is taken up by a pound of the metal to convert it into the liquid condition at the same temperature is what is known as its latent heat of fusion.

In the table below the two columns of figures respectively give the number of units of heat under the Centigrade system and the Fahrenheit system which are required to convert a pound of the substance from the solid at its melting point temperature to that of the liquid. Thus, for instance, one pound of iron will require as much heat to change it from the solid to the liquid at its melting point temperature as would be required to heat up 69 lbs. of water 1° C., or as would be required to heat up 1 lb. of water 124° F. The latter figure can, therefore, be taken as representing the number of British Thermal Units required

to change 1 lb. of iron from the solid condition at its melting point to that of the liquid.

Latent Heats of Fusion

	For Centigrade Scale.	For Fahrenheit Scale.
Aluminium	100·0	180·0
Antimony	40·2	72·36
Bismuth	12·64	22·752
Copper	43·3	77·94
Cobalt	68·0	122·40
Gold	16·3	29·34
Ice	79·77	143·586
Iron—cast-white	23·0	41·40
Iron—cast-grey	33·0	59·40
Iron—pure	69·0	124·20
Lead	5·37	9·666
Magnesium	58·0	104·40
Mercury	2·83	5·094
Nickel	68·0	122·40
Platinum	27·18	48·924
Silver	23·5	42·30
Steel	20·0	36·00
Tin	14·0	25·20
Zinc	22·6	40·68

In the following table the metals are arranged in the order of their respective qualities, the first in the list being the best—

Malleability.	Ductility.	Conducting Power For Heat.	Conducting Power for Electricity.
Gold	Gold	Silver = 100	Silver = 100
Silver	Silver	Copper = 74	Copper = 77·43
Aluminium	Platinum	Gold = 54·8	Gold = 55·19
Copper	Aluminium	Aluminium = 31·33	Aluminium = 34
Tin	Iron	Zinc = 28·1	Zinc = 27·39
Platinum	Copper	Tin = 15 4	Platinum = 10·53
Lead	Zinc	Iron = 11·9	Iron = 11·9
Zinc	Tin	Lead = 7·9	Tin = 11·45
Iron	Lead	Antimony = 4·03	Lead = 7·77
—	—	Bismuth = 1·8	Bismuth = 1·8

TABLE OF WEIGHTS, MELTING POINTS, ETC.

Metal.	Specific Gravity.	Wt. per cu. ft.	Melting point (Cent.)	Linear Expansion for 1° (Cent.)	Specific Heat.	Tensile Strength Tons per sq. in.
Aluminium	2 7	166	659	·0000233	·2143	8
Antimony	6·7	418	630	0000168	·0503	5
Bismuth	9·8	614	271	0000159	·0304	1·3
Brass 70–30	8·1	506	941	0000189	·0939	7·22
Cast iron	7·2	450	1150	0000122		7
Chromium	6 6	414	1615		·1100	
Cobalt	8·7	540	1480	0000123	·1030	33
Copper	8 9	563	1083	0000179	·0951	12
Cadmium	8·6		321	·0000310	·055	
German silver	8 45	527·5				15
Gold	19 31	1203	1063		·0324	9
Invar				0000004		
Iron (molten)	6 88	429	—			
,, (rolled)	7 7	480	1530	0000119	·1138	21
Lead	11 3	710	327	0000295	·0314	1
Magnesium	1·74	109	650	0000276	·2480	
Manganese	7·39	461	1260		·1890	
Mercury	13·6	847	-39		·0331	
Molybdenum	8 6	537	2550		·0720	
Nickel	8·86	553	1452	0000132	·1090	
Osmium	22·48	1403	2700		·0310	
Platinum	21·5	1342	1755	·000009	·0324	14
Rhodium	12·5		1940		·0580	
Silver	10 5		960	0000195	·0570	
Steel (mild)	7·9	490	1500	000011		28
,, (1·4 carbon)			1420			40
Tin (molten)	7·02	438	—		·0562	
,, (cast)	7·29	459	232	0000227		2
Titanium	4·87	304	1795		·1130	
Tungsten	19 3 to 20	1248	3060		·0340	260
Uranium	18·5	1667	1800		·0280	
Vanadium	5·5	337	1720		·1150	
Zinc	7·15	446	419	0000294	·0955	3

Relative Heat Conductivities of Metals and Non-metals

(Calculated on the basis of Silver = 100)

	Relative Conductivity.		Relative Conductivity.		Relative Conductivity.
Silver	100	Iron (Bessemer steel)	8·7	Asbestos paper	·0546
Copper	82·8	German silver	8·09	Air	·0570
Phosphor bronze	66	Lead	6·92	Cotton (compressed)	·0502
Gold	63·8	Antimony	3·65	Cardboard	·0456
Aluminium	44·9	Mercury	2·19	Rubber (para)	·0411
Magnesium	34·3	Cadmium	1·82	Coal	·0370
Tungsten	32·8	Bismuth	1·47	Cotton wool	·0365
Zinc	27·6	Wood's metal (93·86 Bismuth and 6·14 Tin)	1·095	Wood (dry pine and walnut)	·0365
Brass (red)	25·9	Wood's metal (99·05 Bismuth and 0·95 Tin)	·73	Flannel	·0324
Brass (yellow)	23·1	Ice	·456	Paper	·0274
Platinum	17·3	Slate	·438	Slag wool	·0173
Palladium	15·5	Firebrick	·283	Cement	·0148
Iron (wrought)	16·1–11·3	Alumina	·186	Cork	·0119
Iron (pure)	14·7	Glass (crown)	·149	Sawdust	·0110
Tin	13·8	Water	·137	Felt	·00821
Nickel	12·75	Glass (flint)	·130		
Steel (1 % C.)	10·5	Plaster of Paris	·119		

WEIGHTS OF BLACK STEEL PER SQUARE FOOT WITH THICKNESSES IN INCHES AND MILLIMETRES

Gauge	Lbs. per square foot.	Thickness. Inches	Thickness. Mm.
3/16	7·50	·1874	4·770
8	6·28	·1570	3·988
9	5·59	·1398	3·551
10	5·00	·1250	3·175
11	4·45	·1113	2·827
12	3·96	·0991	2·517
13	3·52	·0882	2·240
14	3·14	·0785	1·994
15	2·79	·0699	1·775
16	2·50	·0625	1·587
17	2·22	·0556	1·412
18	1·98	·0495	1·257
19	1·76	·0440	1·118
20	1·56	·0392	·996
21	1·39	·0349	·886
22	1·25	·0312	·794
23	1·11	·0278	·707
24	·99	·0247	·629
25	·88	·0220	·560
26	·78	·0196	·498
27	·69	·0174	443
28	·62	·0156	·396
29	·55	·0139	·353
30	·49	·0124	·315

Weights of Mild Steel Wire

Diameter Inches.	Size on S.W.G.	Diameter: Decimal of an inch.	Diameter: Millimetres.	Approximate weight of 100 feet lbs.
$\frac{1}{2}$	7/0	·500	12·7	66·703
$\frac{15}{32}$	6/0	·464	11·8	57·44
$\frac{7}{16}$	5/0	·432	11·0	49·79
$\frac{13}{32}$	4/0	·400	10·2	42·69
$\frac{3}{8}$	3/0	·372	9·4	36·93
$\frac{11}{32}$	2/0	·348	8·8	32·31
	1/0	·324	8·2	28·01
	1	·300	7·6	24·013
	2	·276	7·0	20·323
$\frac{1}{4}$	3	·252	6·4	16·94
	4	·232	5·9	14·356
	5	·212	5·4	11·99
$\frac{3}{16}$	6	·192	4·9	9·81
	7	·176	4·5	8·256
	8	·160	4·1	6·816
	9	·144	3·7	5·53
$\frac{1}{8}$	10	·128	3·3	4·373
	11	·116	3·0	3·60
	12	·104	2·6	2·876
$\frac{3}{32}$	13	·092	2·3	2·253
	14	·080	2·0	1·703
	15	·072	1·8	1·383
$\frac{1}{16}$	16	·064	1·6	1·096
	17	·056	1·4	·83
$\frac{3}{64}$	18	·048	1·2	·61
	19	·040	1·0	·423
	20	·036	0·9	·343
$\frac{1}{32}$	21	·032	0·8	·273

Weights of Mild Steel Flat Bars

Size.	Wt. in lbs. of 1 ft.	Size.	Wt. in lbs. of 1 ft.
$1'' \times \frac{1}{4}''$	·850	$4'' \times \frac{1}{4}''$	3·400
$2'' \times \frac{1}{4}''$	1·700	$5'' \times \frac{1}{4}''$	4·250
$3'' \times \frac{1}{4}''$	2·550	$6'' \times \frac{1}{4}''$	5·100

Any other size of flat bar can be calculated from the above. Thus, a $2\frac{1}{2}'' \times \frac{3}{8}''$ bar will weigh $1{\cdot}700 + \frac{1{\cdot}700}{2} + \frac{1{\cdot}700}{4} = 2{\cdot}9625$ lbs per foot length.

Weights of Mild Steel Round Bars

Diameter	Wt. in lbs. of 1 ft.	Diameter	Wt. in lbs. of 1 ft.	Diameter.	Wt. in lbs. of 1 ft.
⅛″	·042	½″	·668	⅞″	2·044
¼″	·167	⅝″	1 043	1″	2·670
⅜″	·376	¾″	1·502	1⅛″	3·380

Weights of Mild Steel Angle Bars

Size.	Wt. in lbs. per ft. length.	Size.	Wt. in lbs. per ft. length.
6″ × 6″ × ¾″	28·7	3½″ × 3½″ × ⅝″	13·55
6″ × 6″ × ⅝″	24·18	3½″ × 3½″ × ½″	11·05
6″ × 6″ × ½″	19·55	3½″ × 3½″ × ⅜″	8·45
5″ × 5″ × ¾″	23·59	3″ × 3″ × ⅜″	7·18
5″ × 5″ × ⅝″	19·92	3″ × 3″ × 5/16″	6·05
5″ × 5″ × ½″	16·15	3″ × 3″ × ¼″	4·90
4½″ × 4½″ × ¾″	21·05	2½″ × 2½″ × ⅜″	5·89
4½″ × 4½″ × ⅝″	17·80	2½″ × 2½″ × 5/16″	4 98
4½″ × 4½″ × ½″	14·46	2½″ × 2½″ × ¼″	4·04
4″ × 4″ × ¾″	18·49	2¼″ × 2¼″ × 5/16″	4·45
4″ × 4″ × ⅝″	15·66	2¼″ × 2¼″ × ¼″	3·61
4″ × 4″ × ½″	12·75	2″ × 2″ × ¼″	3·19
4″ × 4″ × ⅜″	9·72	2″ × 2″ × 3/16″	2·43

Weights of Mild Steel Tee Bars

Size.	Wt. in lbs. per ft. length.	Size.	Wt. in lbs. per ft. length.
6″ × 3″ × ½″	14·53	4″ × 3″ × ½″	11·08
6″ × 3″ × ⅜″	11·08	4″ × 3″ × ⅜″	8·49
5″ × 4″ × ½″	14·51	3½″ × 3½″ × ½″	11·08
5″ × 4″ × ⅜″	11·07	3½″ × 3½″ × ⅜″	8·49
5″ × 3″ × ½″	12·79	3″ × 3″ × ½″	9·38
5″ × 3″ × ⅜″	9·78	3″ × 3″ × ⅜″	7·21
4″ × 5″ × ½″	14·50	2½″ × 2½″ × ⅜″	5·92
4″ × 5″ × ⅜″	11·06	2½″ × 2½″ × ¼″	4·07
4″ × 4″ × ½″	12·78	2″ × 2″ × ¼″	3·30
4″ × 4″ × ⅜″	9·77	1½″ × 1½″ × ¼″	2·50

Hardness of Metals. Although the hardness of a substance is one of the commonest properties spoken of and understood, yet it is one of the most difficult to accurately measure. The hardness of a metal can be considered in several different ways, all of which give more or less different comparative results.

(1) A metal may be scratched or cut, the degree of hardness being measured by the depth of the scratch under uniform pressure.

(2) The hardness may be measured by the diameter of indentation made by a steel ball pressing with a definite load.

(3) It may also be measured by the height of re-bound of a hard steel ball falling upon its surface.

The hardness of several metals measured by the third method indicated are as follows—

	Shore's Scleroscope.
Hard Steel	95
Hard White Iron	70
Hard Cast Iron	40
Rail Steel	27
Soft Cast Iron	24
Mild Steel	22
Soft Iron	12
Copper	8
Zinc	7
Tin	3
Lead	1–0

A study of the varying hardness of the constituents that are set up in steel under certain conditions of heating and cooling is interesting. The relative hardness of these, taking pure iron as unity, is as follows—

Ferrite	1
Pearlite	4·3
Sorbite	52·0
Troostite	88·0
Austenite	104·0
Martensite	239·0
Cementite	272·0

Bursting Pressure of Cylinder or Tube. The bursting pressure in pounds per square inch of a cylinder or tube can be found by multiplying the thickness of plate by its tensile strength per square inch in lbs., and dividing the result by the radius, in inches. Thus, the bursting pressure

per sq. inch of a solid drawn tube, 8 inches diameter and $\frac{1}{4}$ in. thick, made from steel of 28 tons to the square inch, tensile strength would be—

$$\frac{\frac{1}{4} \times 28 \times 2240}{4} = 3920 \text{ lbs.}$$

If, however, it were jointed with a single-riveted longitudinal seam, its strength would be reduced to the proportional strength of the joint, which would be about 50 per cent of the plate.

To Find Contents of Gas Cylinder. This can be worked out very simply by the application of what is known as " Boyle's Law," this for our purpose being defined as " The pressure of a given quantity of gas varies inversely as its volume if the temperature be constant."

From this it will be seen that the quantity of gas in a cylinder which is, of course, a fixed volume will be directly proportional to its pressure. Thus if a 100 ft. oxygen cylinder has its pressure reduced from 120 Ats. to 30, its contents will be 25 cu. ft. of oxygen.

The pressure of a fixed volume of gas also increases or decreases according as the temperature is increased or decreased. For every 1° C. increase in temperature the pressure of the gas will increase 1/273 or ·00366 of its total pressure. Or for every 1° F. increase in temperature it will increase in pressure 1/492 or ·00204.

WEIGHTS OF GASES

	Density.	Cubic feet to 1 lb. at At. pres.
Air	1	12·38
Acetylene	·91	13·65
Carbon Dioxide	1·529	8·1
Chlorine	2·44	5·07
Coal Gas	·453	28·27
Hydrogen	·07	178·3
Oxygen	1·105	11·2

Quantity of heat given out, in B.T.U.'s of 1 lb. weight of various gases, when completely burnt—

Hydrogen	62100
Carbon to CO_2	14647
,, to CO	4480
CO	4383
Methane	24017
Ethylene	21898
Acetylene	21856

Electrical Data

Volt = unit of pressure. It is the electrical pressure which will produce a one-ampere current through a one ohm resistance.

Ampere = unit of current. It is the current which when passed through a solution of nitrate of silver, deposits silver at the rate of ·0011181 grams per second.

Ohm = unit of resistance. It is the resistance offered to an electric current by a column of mercury 106·3 cm. long and 14·4521 grams in weight.

Watt = unit of energy. It is the energy expended per second by a current of one ampere under a pressure of one volt.

$$\text{Amperes} = \frac{\text{Volts}}{\text{Ohms}}$$

1 horse-power = 746 watts.

1 kilowatt = 1000 watts = $1\frac{1}{3}$ horse-power.

Electrical Resistance of Metals

(Cubic centimetre at 18° Centigrade)

Aluminium . .	2·94	Magnesium .	4·12	Tungsten . .	4·81
Antimony . .	40·5	Mercury . .	95·57	Zinc . . .	6·1
Bismuth . .	119·0	Molybdenum .	4·1	—	
Cadmium . .	7·54	Steel . . .	19·9	Alloys . .	
Copper (annealed)	1·58	Nickel . .	11·8	German silver .	26·6
,, (hard) .	1·61	Osmium . .	9 5	Nichrome .	95·5
Cobalt . .	9·71	Palladium . .	10·7	Brass . .	6·6
Gold . . .	2·42	Rhodium .	6·0	Constantin . .	49·0
Iron (annealed) .	9·7	Platinum . .	11·0	Manganin . .	43·5
,, (wrought) .	14·0	Silver . .	1·65	Phosphor bronze	7·5
Lead . .	20·8	Tin . . .	11·8	Wood's alloy . .	31·25

Rough Determination of Temperature by Colour

Dark red—just visible	900°F. =	482°C.
Blood ,,	1050°F. =	566°C.
Full ,,	1375°F. =	746°C.
Bright ,,	1550°F. =	843°C.
Orange	1725°F. =	941°C.
Yellow	1825°F. =	996°C
Yellow—light	1975°F. =	1078°C.
White heat	2200°F. =	1204°C.
White welding heat	2600°F. =	1426°C.
White—dazzling	2800°F. =	1538°C.

Useful Data

1 inch = 2·54 centimetres.
1 gallon = 277·274 (277¼ nearly) cubic inches.
1 cubic foot = 6¼ gallons.
1 cubic foot of fresh water weighs 62·3 lbs.
(In ordinary calculations 62½ is used.)
1 cubic foot of sea water weighs 64 lbs.
1 gallon of fresh water weighs 10 lbs.
1 gallon of sea water weighs 10¼ lbs.

1 lb. of iron	= 3·6	cubic inches.
1 ,, ,, cast iron	= 3·9	,, ,,
1 ,, ,, copper	= 3·23	,, ,,
1 ,, ,, Brass	= 3·3	,, ,,

Sizes of Welding Wires and Rods

Thickness of Sheet, Plate, or Bar to be welded, in gauges or inches.	Suitable size of Welding Rod in S.W. gauge.
No. 22 S.W.G.	No. 22 S.W.G.
20 S.W.G.	20 S.W.G.
18 S.W.G.	18 S.W.G.
14 S.W.G.	14 S.W.G.
10 S.W.G.	10 S.W.G.
3/16"	9 S.W.G.
¼"	7 S.W.G.
⅜"	5 S.W.G.
½"	3 S.W.G.

For electric welding the gauge of the electrodes usually runs from No. 14 up to No. 6, the diameter of the electrode chosen depending upon the thickness of the plate and the method of welding adopted.

The common sizes of wire used in welding are usually No. 10 and No. 8 gauge, as it simplifies matters to keep to the least number of wires. The 10 gauge can be used for the first run on the Vee, and the heavier gauge for the later runs.

The Mechanical Testing of Iron and Steel

The engineer who has charge of welding work and the intelligent welder himself ought to know something of the mechanical and physical properties of iron and steel and the way in which they are measured.

Tensile Strength. The strength of a bar of metal can be defined as the greatest load which can be applied in an effort to pull it asunder longitudinally. For purposes of comparison this is usually calculated as the load per square inch of cross section, and is then called the maximum unit stress. This stress per square inch is calculated by taking the breaking load of the bar and dividing it by the area. Thus, to give an illustration, a $1\frac{1}{2}$ in. diameter bar of mild steel broke with a load of 43 tons. The load divided by the area of a $1\frac{1}{2}$ in diameter circle equals 24·38 tons, this latter figure can then be referred to as the tensile strength per square inch of the bar.

When testing bars in a tensile testing machine it is usual to allow the bar to break with the maximum load on the beam, and this is the load which is always taken for calculating the ultimate tensile strength of the material. But whilst the bar is drawing out or lengthening in the testing machine through its plastic stage, it will be found that a less load than the maximum will carry on this stretching and ultimately break the bar. This lesser load is only used for calculating the actual breaking stress per square inch on the reduced area of the bar and is only used for very special purposes.

Elastic Limit, Limit of Proportionality, Elongation, Yield Point, and Reduction of Area. When a bar of iron or steel

is placed in a testing machine and an increasing load gradually applied, it is found that the bar commences to stretch, and up to a certain point if the load be taken off it will be found that the bar will come back to its original length. Thus, in mild steel of about ·10 per cent carbon which has a breaking stress of about 22 tons per square inch, it is found that it can be loaded up to about 12 tons per square inch, and then if the load is removed it will come back to its original length, but if the load is increased more than this, say up to 15 or 16 tons per square inch, and then removed, it will be found that the bar will be permanently lengthened. The 12 tons referred to above would be called its *limit of elasticity,* or more correctly its *limit of proportionality.*

The term limit of elasticity is now being displaced by the other term mentioned, as if the load be removed at any stage of the testing it will be found that the bar springs back a little in its length, showing that it is elastic at all points in the loading. If careful tests were made on such a bar as is mentioned above it would be found up to the limit of 12 tons that the stretch or strain will be proportional to the load. Thus, with a 12 ton load the bar would stretch about 1/1000 of its length, and if the test piece be 10 ins. long this would be 1/100 in., but if the stretch on the bar were measured when half of the above load—6 tons—were applied, it would be found that this would amount to one-half of that with the 12 tons, 1/200 in. only.

Therefore, it will be seen that up to the limit of proportionality the actual amount of stress on a bar is very small indeed, and requires very careful measurement for it to be determined accurately. This is usually measured by some form of extensometer, which largely multiplies the amount of stretch. One of the best known of these is the Ewing's instrument.

From very careful tests that have been made it is found that the real limit of proportionality is somewhat lower

than it is usually taken to be from observing the lengthening of the bar in the testing machine.

After a bar in a testing machine has reached its limit of proportionality the amount of strain is then greater in proportion than the increased load, and it then arrives at its *yield point*, which means there is a fairly large jump in the length of the bar with very little increase in the applied load. With a slight increase of load the bar now lengthens considerably and has arrived at what is known as its plastic stage, when it will go on stretching until it ultimately breaks.

The *elongation* of a test piece is denoted as a percentage increase on the length of the bar. Thus, to give the record of a test on a piece of ·40 per cent carbon steel—

Dia. of Bar.	Breaking Load in Tons.	Tensile Strength in Tons per sq. in.	Elastic Limit. Tons per sq. in.	Yield Point. Tons per sq. in.	Elongation. % on the length of 8 Diameters
·944"	25 6	38·05	22·9	23·18	26·6

Whilst the practical limit of proportionality is given as 22·9 tons, it is very probable that with accurate testing this would come down to about 19 tons per square inch. Generally, the limit of proportionality of plate and bar steel may be taken to be from 50 to 60 per cent of the tensile strength. With very low carbon steel the elongation will run up to as much as 45 per cent of the length of the test piece.

The tensile strength and the limit of elasticity of a steel, it should be remembered, can be considerably altered by any form of cold work which is done on the steel, or heat treatment, such as tempering or quickening the natural rate of cooling bars or plates.

When a bar is pulled in a testing machine until it breaks it will be noticed there is considerable reduction in the

diameter of the bar at the point of fracture. This reduction of area is usually expressed as a percentage of the original cross-sectional area of the bar. The softer and more ductile the material the greater, of course, will be the percentage reduction of area, and this property of a reduced area at the fracture is usually taken to be a good indication of the ductility of the material.

Modulus of Elasticity. This is a term which is often imperfectly understood. We mentioned above that as soon as a bar of mild steel is loaded it commences to stretch, and this stretching goes on in proportion to the load up to its limit of proportionality. Now if it can be imagined that a bar will remain perfectly elastic until it stretches *twice its length* it can be calculated that it would require a load of about 13,000 tons per square inch to produce this result. This load is called the modulus of elasticity. Whilst the stretching of a bar to twice its length is, of course, quite imaginary, the modulus serves a useful purpose in enabling us to calculate the actual increase in length of a bar of iron or steel where any load is placed on same which is less than that which would cause a permanent set.

CHAPTER XXII

THE TRAINING OF WELDERS

The proper training of welders presents many difficulties on account of the very varied classes of work to be done, and also the great variation in the types of youths and men who seek to become welders. Generally, the best welders are those who are recruited from the various metal-working trades. A beginner at any form of welding processes who has received some training in the use of tools and the working of metals, certainly has a great advantage over one who has had no such training. But even a good all-round mechanic at times finds it difficult to obtain the necessary training to become a first-class welder. This may be due to not being able to obtain the right kind of workshop practice or the necessary training in a welding school. Welders usually sort themselves out into categories and settle down to one or more classes of work. A very few become good all-round welders who are not afraid to tackle almost any kind of work. There is certainly room for this latter class of welder, but in the main if particular kinds of work require to be done there is more certainty in the results if the operator has specialized on this class of work. It should not be forgotten that the highest type of welder, like the best kind of mechanic, is one who has cultivated a peculiar "sense" of producing first-class work.

No training in a technical school is sufficient in itself to produce a good welder. This training must only be looked upon as ground work and must be supplemented by good workshop experience. Engineers who are likely to become supervisors over welding work will obtain distinct benefit from a course taken in both the theory and practice of

welding at a good technical college. Draughtsmen who ɥve to design structures with welded joints should cer-inly have some knowledge both of the theory and practice ! welding.

An ambitious welder should become acquainted with the ɥrious kinds of welding processes and operations that are ow in use, and should endeavour to learn how to use oth the oxy-acetylene and electric-arc methods of welding, s a first-class workshop ought to be fitted out with both inds of plant.

Syllabus for a Course of Training. It is very much easier to draw up a list of subjects to be learnt and a course of practical training to be followed, than to arrange facilities for the scheme to be carried out. Where technical colleges have the ways and means of holding suitable classes, and the right type of students present themselves, the Syllabus of the City and Guilds of London Institute is excellent for the purpose, and a good practical welder who passes the Institute's examinations ought to be a high-class man.

In the first place, a knowledge of possible dangers and their avoidance should be obtained, and for this purpose there is nothing better than the Factory Department, Home Office, *Memorandum on Safety Measures Required in the Use of Acetylene Gas and in Oxy-acetylene Processes in Factories.* This can be obtained direct from H.M. Stationery Office or from leading stationers, price 2d. net. It explains how explosions may occur in the use of gener-ators, hydraulic valves, cylinders, etc., and also mentions the dangers in welding to the eyes, skin, etc. It also gives particulars in regard to the storage of carbide of calcium, and the various precautions which should be taken in connection with acetylene generating plant, and the other kinds of apparatus which are used in connection with welding. There is also a *Memorandum on Electric Arc Welding*, price 3d. net, which deals with the following points—

Use of both direct and alternating current in connect with arc welding. The comparative dangers of the t kinds of electric current. Risks of shock. Special ri which may be set up by working on stagings, boilers, e The injurious effects of radiations, and the precautic which should be taken against these, and also agai chipping of slag, fume in confined spaces, and so on.

The various methods of jointing metals and the differ types of joints which are used in welding plates, pi bars, etc.

Acetylene and its properties. Generators: their c struction and use. The atmosphere and its relation welding. Oxygen and its properties. Iron and steel: tl manufacture and composition, and effect of the latter welding. The physical and chemical properties of met and their relation to welding processes. Electric weld equipment and the various points of importance in maki electric welds. Defects in welds and how to avoid th Blowpipes and regulators: their construction and Feed wires and electrodes: their manufacture, composit e and effect on quality of welds. Gas cylinders: their differ tiation, strengths, and treatment. Copper: its manufact properties, and methods of welding. Aluminium: its man facture, properties, and methods of welding. Ferrous a non-ferrous alloys: their compositions, properties, uses and methods of welding. Causes of the corrosion of meta and treatment to resist same. Annealing, hardening, ter pering, and case-hardening of iron and steel. Ty of furnaces used in metallurgical and welding proces and the various kinds of fuel or other sources of hea generation.

Workshop Course. The first part of the course shoulc consist of a thorough training in the making of welds in thin sheet and plate work. Welding of flat bars and the testing of same by bending in the vice over a mandrel and also the tensile testing to find the efficiency of a weld as

ompared to the strength of the plate or bar from which is made. The jointing of artistic ironwork. Pipe jointing. ertical and overhead welding. The welding of cast-iron, luminium, and aluminium alloy. The welding of copper, rass, bronze, and other alloys. Experimental work in the velding of stainless steels, monel metal, and other special lloys. The cutting of metals by the blow-pipe and electric c. The proper testing of all kinds of welds should form important part of the workshop training.

Electric welders should be encouraged to deposit pads metal, and to make an examination of these by sawing hrough, polishing the section, and making a visual examation of the surface both before and after it has been ched by a weak acid. The more experienced of the elders in training should be encouraged to examine weld eposits and the metal adjoining the welds by the proection microscope. Under an experienced tutor quite a t of useful and interesting tests can be made by the aid the microscope, but this is not of much interest without image is projected on a screen, and the examination ade by a group of welders who can ask questions and iscuss the various points raised. Test pieces from all eposited weld metal should also be made, and these tested for tensile strength, elongation, reduction of area, also bending and shock tests carried out.

Regulations and Specifications

In addition to the memoranda already mentioned, there are all kinds of regulations and specifications with which the welder should be conversant. Thus, the following are extracts from the Regulations for the Sale and Purchase of Carbide of Calcium as drawn up by *The Institution of Welding Engineers*—

Guaranteed average gas yield of raw acetylene per kilogramme of carbide, corrected to a barometric pressure

of 760 mm. of mercury and a temperature of 15° C., shall be—

For the size	80/120 mm.	290 litres per kg.	(4·64 cub. ft. per lb.)
,,	50/80 mm.	290 ,, ,,	(4·64 ,, ,,)
,,	25/50 mm.	290 ,, ,,	(4·64 ,, ,,)
,,	15/25 mm.	275 ,, ,,	(4·4 ,, ,,)
,,	7/15 mm.	270 ,, ,,	(4·33 ,, ,,)

The sizes in millimetres can be converted into inches by taking 25·4 mm. to equal 1 in. Thus the sizes 7 to 15 mm. will be nearly equal to $\frac{5}{16}/\frac{5}{8}$ in.

Dust. Carbide of the sizes between 8 mm. and 120 mm. shall not contain more than 5 per cent by weight of dust, which shall be defined as carbide passing through a mesh of one square millimetre.

Impurities. Carbide shall yield acetylene containing not more than—

0·05% by volume of phosphuretted hydrogen (PH_3)
0·15% ,, ,, sulphuretted hydrogen (SH_2)

There are several other clauses which deal with the sampling, testing, etc. These should be carefully perused, and also the Regulations drawn up by *The British Acetylene Association.*

British Standards Institution. There are several publications issued by the above Institution which are of interest to all classes of welders. Thus No. 499—1933 deals with the terms, definitions, and symbols used in connection with welding and cutting. It gives illustrations of all the various kinds of joints used in connection with welding.

Publication No. 487—1933 gives the specification for the manufacture of fusion welded steel air receivers, showing illustrations of the various forms of welded joints which can be used in that class of work.

There are several other publications which deal with structures, electrodes, and so on, which a welder will find useful.

Publication No. 349—1930 gives a full list of the identification colours for gas cylinders. Thus—

Acetylene	is	Maroon
Air	,,	Grey
Coal Gas	,,	Red
Hydrogen	,,	Red
Oxygen	,,	Black

There are no less than twenty-five colours tabulated to distinguish the various kinds of gases which are used in industry.

The British Corporation Register of Shipping and Aircraft, and also *Lloyd's Register of Shipping* have rules which govern electric welding in ships. These should both be carefully perused by those who have to carry out work in connection with the building or repair of ships.

The Institution of Welding Engineers holds meetings for the reading of papers, discussions, etc., and issues reprints of its lectures. Connection with this Institution is always of great help both to the welder and the welding consultant.

For the benefit of students both in welding and engineering generally a reprint follows of the examinations in the *Theory of Welding* which have been held at the Liverpool City Technical College during the last few years.

EXAMINATION QUESTIONS

EXAMINATION QUESTIONS 1

1. Name the various pieces of apparatus contained in an oxy-acetylene welding equipment in which generated acetylene is used, and state the purpose of an hydraulic back-pressure valve.

2. Draw a diagram showing the essential parts of any acetylene generator with which you are acquainted. Briefly describe the action of the generator.

3. How much acetylene should 1 lb. of carbide produce? State at what pressure should it be delivered for welding in the low-pressure system?

4. Give the composition of acetylene. (*a*) What are its principal impurities, and how are these removed? (*b*) What is their effect on a weld? (*c*) How can you roughly test acetylene for impurities?

5. State the difference between the high- and low-pressure systems of welding, and state the conditions of working when it would be an advantage to use the high-pressure system.

6. Clearly express what is meant by the term "Dissolved Acetylene." State the maximum pressure at which this may be put up in cylinders; also state the usual pressure to which it is reduced for use with (*a*) a cutting blow-pipe; (*b*) a welding blow-pipe.

7. Explain (*a*) How you would regulate the blow-pipe flame to give the best results in welding? (*b*) How is a joint affected by bad blow-pipe flame regulation?

8. To what pressure are oxygen cylinders usually charged, and why is it necessary to use pressure regulators on these cylinders?

9. Describe the process of metal cutting by oxygen and the appliances used for that process. How does the oxygen "cut" the metal?

10. A crack about 3 in. long has shown up in one of the mild steel plates of a tank; carefully explain how you would proceed to repair this so as to leave the plate in the best possible condition.

EXAMINATION QUESTIONS 2

1. Write out a statement giving particulars of what you would require for an oxy-acetylene welding equipment, in which generated acetylene is used, to cover the requirements of one operator both for light and heavy work. Carefully explain the action of the hydraulic back-pressure valve.

2. Clearly and briefly describe, with diagram, the action of any acetylene generator with which you are acquainted. At what pressure should it deliver gas for welding purposes? State the disadvantages that accrue when the pressure gets very low.

3. Give the chemical composition of carbide and state the impurities it usually contains and how these affect the acetylene generated. How many cubic feet of acetylene should 1 lb. of pure carbide produce? How much is usually obtained in practice and why is it so low?

4. State the difference between the high- and low-pressure systems of welding, and carefully tabulate the advantages and disadvantages of each system as compared to each other. Give illustrations of the use of each system in practical working.

5. State the precautions that have to be taken when charging dissolved acetylene into cylinders. State what the acetylene is dissolved in, and the amounts that can be dissolved at definite pressures. What is the maximum pressure allowable for acetylene in cylinders?

6. Write out a careful statement explaining the correct proportion of acetylene and oxygen it is necessary to have in the blow-pipe flame to give the best effect in welding. State what happens to a welded joint when a reducing flame is used, and also when it becomes oxidizing.

7. Draw a careful diagram giving details of any kind of blow-pipe with which you are familiar. State some of the causes of back-firing in a blow-pipe.

8. If you had three cylinders containing respectively oxygen, hydrogen, and coal gas, how could you detect one gas from the other apart from the marks on the cylinders and the right- and left-hand threads on the nozzle?

9. A good deal of difficulty is experienced in testing a weld that is made on an actual job. Carefully explain what precautions should be taken to ensure that the weld is sound, and also explain any kind of test that it is possible to apply to the weld in position.

10. Explain clearly how you would repair a crack in a piece of cast-iron work, and also how you would make a welded joint in copper plate.

EXAMINATION QUESTIONS 3

1. Name the various methods of welding that are in use and state the advantages that acetylene welding has over some of them.

2. Give an outline sketch of any type of blow-pipe with which you are familiar, and explain how the gases are mixed.

3. Show by sketches how to obtain the best condition of blow-pipe flame for welding. State the causes of the flame getting out of adjustment whilst the blow-pipe is being worked.

4. Explain in detail, with sketches, the preparation of joints of various kinds for welding. What are the disadvantages of too small a V and too large a V in plate jointing?

5. Explain in detail the kind of tests you would apply to welded test bars so as to ensure the highest quality of welding.

6. State some of the causes of a "back-fire" and how you would proceed to act if this should happen. How can "back-fires" be avoided?

7. In the use of gases for welding and cutting several explosions have occurred. Explain the causes of these and what precautions should be taken to avoid explosions.

8. What are the pressures to which dissolved acetylene and oxygen cylinders are charged? What is the usual pressure at which acetylene is delivered from a generator? How are the pressures regulated for blow-pipe use?

9. Write out a careful statement explaining the causes of the various defects that may be found in welds.

10. Give a description of the process of metal "cutting," and explain the purpose served both by the acetylene and the oxygen used in the cutting blow-pipe.

EXAMINATION QUESTIONS 4

1. Name the various methods of metal jointing, riveting, welding, etc., that are in use, and clearly state the different ways in which acetylene welding has an advantage for many purposes.

2. Give a diagrammatic sketch of two types of blow-pipe, carefully explaining how the right mixture of gases is obtained. What is it that stops the gas from firing back to the mixing chamber?

3. Make sketches of the blow-pipe flame when it is of an oxidizing character, when of a carbonizing character, and when the flame is neutral. What is the difference between the inner and outer zones of the flame, and what is the cause of this difference?

4. Explain in detail, with sketches, the preparation of joints for various kinds of welding jobs. What are the disadvantages of too large and too small a V in plate jointing, and in what cases should the double V be used?

5. Explain carefully the kind of tests you would apply to welded test bars so as to ensure the highest quality of welding. What kind of test would you apply to an actual welded job?

6. Under what conditions would a "back-fire" be set up in a blow-pipe, and what immediate action should be taken if this happened? Explain the various devices that are in use as a precautionary measure against back-fires.

7. You are aware that many accidents have happened in connection with the use of carbide, acetylene, hydrogen-oxygen, etc., explain the causes of these explosions, and state what precautions should be taken to obviate the occurrence of same.

8. What are the usual pressures to which dissolved acetylene and oxygen cylinders are charged? What is the limit of pressure at which free acetylene can be stored, and what are the essential precautions that have to be taken in the charging and use of dissolved acetylene cylinders?

9. Examination of the micro-structure of welds in many cases reveals defects, explain the cause of these defects and how they can be avoided.

10. Explain clearly the chemical action which takes place in cutting mild steel by the oxy-acetylene blow-pipe. Why is it so difficult and in some cases impossible to "cut" other metals by this process?

EXAMINATION QUESTIONS 5

1. State all the precautions that you would consider it necessary to take to guard against any possible form of explosion or other source of danger that is likely to be brought about through any form of carelessness in the use of an oxy-acetylene plant.

2. Explain the working of any kind of generator with which you are acquainted, and state why it is necessary to purify the gas before it passes on to the blow-pipe.

3. Why is it necessary that the carbide chamber of a generator should not be completely filled with carbide? Also explain how you would treat the residue from the chamber.

4. If you were given three different kinds of blow-pipes with the request to test them for practical purposes, state

clearly the tests you would make, and the methods you would adopt to find out which of the three blow-pipes was the best.

5. Clearly explain what is meant by the term "Dissolved Acetylene," and state the maximum pressure to which this is compressed in cylinders. What are the advantages and disadvantages in the use of dissolved acetylene as compared with acetylene direct from generators?

6. State the maximum pressure at which oxygen is usually sent out in cylinders. Also explain what is meant by the statement "A cylinder contains 100 cub. ft. of oxygen." What should be about the weight of this quantity of the gas?

7. Why is it necessary to use a regulator in connection with an oxygen cylinder? Is there any need to use a pressure gauge in connection with the same? If not, explain the uses to which a pressure gauge can be applied.

8. What precautions should be taken so as to ensure that a weld is neither oxidized or carburized? How can an oxidized weld be detected?

9. Steel and iron expand and contract with changes of temperature. How does this affect welding operations, and what can be done to overcome the possibility of any defects that may be set up?

10. A plate of mild steel is 10 ft. long by 4 ft. wide by 1 in. thick, and it is required to "cut" a hole 12 in. diameter in the centre of same. Carefully explain how you would proceed to carry out the job.

EXAMINATION QUESTIONS 6

1. Oxy-acetylene, oxy-petrol, and electric-arc methods of welding and cutting are now being applied to all classes of work. Compare these methods and particularly explain the advantage that acetylene welding has for certain classes of work.

2. What is it that causes a "back-fire" in a blow-pipe, and under what conditions is it possible for a back-fire to travel along to the generator? What precautions should be taken to overcome this danger?

3. In making comparative tests on blow-pipes which type of flame would you choose as giving the best result? Give particulars of the method you would adopt in making and testing specimen joints so as to choose which blow-pipe is giving the best result.

4. Give the chemical composition both of carbide of calcium

and acetylene, and explain the chemical reaction that takes place when acetylene is generated. How many cubic feet of acetylene should 1 lb. of pure carbide produce, and how much is usually obtained from commercial carbide in practice?

5. What are the methods that are at present in use for the manufacture of oxygen? State the impurities that are usually found in this gas as produced by the different methods. What effect have the impurities upon welding and cutting?

6. Explain the chemical reaction which takes place in the blow-pipe flame. Also give the correct proportion of acetylene and oxygen it is necessary to supply to the flame to give the best effect in welding. How can you tell when a joint is oxidized?

7. If you were in charge of a welding department what methods would you adopt to ensure that the work turned out was of the highest quality?

8. Much difficulty is at times met with in overcoming expansion and contraction in cast iron articles which have to be welded. Give particulars of any important job which you have carried out and the methods you adopted so as to ensure that there would neither be fracture or distortion after the job was finished.

9. Write a short essay on welding rods and wires as used for wrought iron, mild steel, cast iron, and copper. How does the varied quality of these affect the resulting weld?

10. Give particulars of how you would carry out a repair on either an aluminium or an aluminium alloy article. State the kind of feed wire or rod you would use and kind of flux, and also the precautions you would take so as to make sure the resulting work would be of the highest quality.

EXAMINATION QUESTIONS 7

1. Write out a list of all the necessary parts of an oxy-acetylene equipment in which dissolved acetylene is used, stating the use of each particular part.

2. Give a diagrammatic sketch of any type of acetylene generator, and state the precautions you would take in starting it up.

3. State the method you would adopt in opening a drum of carbide, and explain the precautions you would take so as to ensure safety in handling both drums that contain carbide and those that are empty.

4. What are the maximum pressures in oxygen and acetylene

cylinders? At what pressures are these gases usually delivered to the blow-pipe?

5. Give a sketch of the kind of blow-pipe flame which you consider is suitable for welding mild steel. State why the flame sometimes alters whilst the blow-pipe is being used.

6. Describe how you would proceed to test any kind of weld that you had made either in wrought iron or mild steel work. State some of the common defects in welds.

7. State the difference between cast iron, wrought iron, and mild steel. How can you tell the difference between the latter two metals?

8. Make a sketch of a hydraulic back-pressure valve, clearly showing the arrangement of pipes and cocks. What is the particular purpose of the valve and in what condition should it be kept so as to be effective when required?

9. If you had to weld a diagonal stay at two corners of a square angle iron frame, state what method you would adopt to overcome distortion through the contraction which would take place after welding.

10. Carefully explain how you would carry out the "cutting" of a 7-in. diameter wrought iron bar.

EXAMINATION QUESTIONS 8

1. Give a description of the various methods that are in use for the jointing of metals, including the different kinds of welding.

2. Give particulars of a "water to carbide" generator and also a "carbide to water" generator, and show by sketches how each of these operates.

3. Through carelessness explosions have occasionally occurred in connection with oxy-acetylene welding. Explain the various precautions you would take to avoid any form of danger.

4. Both the high-pressure and low-pressure systems of oxy-acetylene welding are in use in this country. State the advantages and disadvantages of each system for particular kinds of work.

5. To what maximum pressures are the gases in acetylene and oxygen cylinders usually compressed, and what quantities of gases do cylinders usually contain? How would you distinguish an oxygen cylinder from other kinds of cylinders?

6. In what ways are hydraulic back-pressure valves likely

to become defective, and if defective, what results are likely to follow?

7. Make careful sketches explaining how you would prepare the edges of plates for a welded pipe of $\frac{1}{4}$ in. thickness. If the pipe was 6 ft. long and 8 in. diameter, carefully explain how you would carry out the welding of the seam.

8. Give a diagrammatic sketch of a blow-pipe and explain how the gases become properly mixed before they pass to the flame. What effect would the enlargement of the hole in the blowpipe nozzle have upon the flame and the work which was being carried out?

9. If you were asked to give a demonstration of the quality of your welding, explain the kinds of tests you would apply both to mild steel and cast-iron welds.

10. Give some of the causes, apart from the operator, which may bring about bad welds in either wrought iron, mild steel, or cast iron.

EXAMINATION QUESTIONS 9

1. Give a general description of the various methods that are in use for the jointing of metals, stating their advantages and disadvantages and applications to various classes of work.

2. Compare the different types of generators, briefly stating their advantages and disadvantages. How would you proceed to test a generator, and how would you judge the quality of the generator from the results obtained?

3. Explosions and fires occasionally happen in connection with the use of gases for welding purposes. Give illustrations of any dangerous conditions which may be set up, either through carelessness or otherwise, and how these may be guarded against.

4. Show by sketches the different kinds of flame that you can obtain with a blow-pipe, and briefly explain the effect which each of these flames would have upon the quality of the weld made in mild steel.

5. Give a description of the kind of cylinders that are used for the storage of acetylene and oxygen and explain how you would tell the quantity of the respective gases contained by these cylinders. Is there any disadvantage in taking the gases from the cylinders at a very quick rate?

6. Explain the methods that are adopted both in connection with the blow-pipe and the acetylene supply to avoid back-firing to the generator. Back-fires from the blow-pipe

to the hydraulic valve occasionally happen, explain the cause of them.

7. Explain how you would weld together the edges of two flat sheets of mild steel 4 ft. long, in such a way as to keep the sheets as flat as possible. If the sheet was of 20 gauge what kind of joint would you use?

8. Give some detail of the kinds of defects that may be set up in the welding of mild steel, copper, and aluminium. State the causes of these defects and how they may be overcome.

9. Give particulars of any kind of important piece of welding work, either in cast iron, aluminium, copper, or brass, which you have carried out, explaining in detail the various precautions taken so that the resulting work should be of the best quality.

10. Carefully discuss the various factors which go to the making of good or bad welds in either cast iron or aluminium alloy, and state what kind of test you would apply to work of this description.

EXAMINATION QUESTIONS 10

1. Show by sketches how you would cut and treat a piece of 2-in. wrought iron pipe to form a right-angle bend by welding.

2. Explain all the precautions you would take in connection with a generator and the use of acetylene for welding purposes so as to avoid any possibilities of explosion or accidental burning.

3. Through want of care and the exercise of thought generators are sometimes found to be in very inefficient condition. Explain all the working parts about a generator which should receive regular and careful attention so that it will work in the most efficient and safe manner.

4. Show by sketches the kind of blow-pipe flame which gives the best result in the welding of mild steel or wrought iron. Explain why the flame sometimes alters during working conditions.

5. About what quantity of carbide should be added to the charging chamber of a generator? What is likely to happen if the charge of carbide is too great?

6. The careless handling of both oxygen and acetylene cylinders sometimes causes them to be defective or set up an explosion. Explain all the necessary precautions that should be taken in the handling and use of cylinders.

7. Explain the essential difference between cast iron, wrought iron, and mild steel.

8. State all the necessary precautions you would take in making a weld in mild steel so that it would be as strong and tough as possible.

9. If you are making a weld in cast iron state the various points that should be carefully noted so as to ensure that the weld is not only solid, but that there is little or no danger of fracture after it is finished.

10. Explain the various ways in which the atmosphere affects welding operations either to their advantage or disadvantage.

EXAMINATION QUESTIONS 11

1. If you were about to start an oxy-acetylene welding shop of your own using generated acetylene, state the various regulations it would be necessary to comply with and also the precautions that should be taken to ensure safe working.

2. What particular properties do the gases, oxygen, and acetylene, possess as compared with other gases which enable them to be used so extensively for welding purposes?

3. Explain how you cut and prepare pieces of 2-in. drawn copper pipe so as to make a welded Tee-piece. State how you would carry out the welding of the joint.

4. What part does the atmosphere play in oxy-acetylene and electric-arc welding? In what ways is its presence beneficial or detrimental to the making of a weld?

5. If you have charge of an acetylene generating plant, carefully explain all the points which should be watched so that the plant is run as economically and efficiently as possible.

6. What particular advantage accrues from the use of pure acetylene? Explain how the gas is purified and what is removed from it in the purifying process.

7. Explain how you would make and weld test pieces in mild steel plate by either the oxy-acetylene or electric-arc processes, and state the various ways by which you would test such pieces to ensure obtaining the best quality of joint.

8. Give particulars of one or two kinds of blow-pipes that are in use, and state what you know as to the developments

that have taken place in connection with the designing of blow-pipes during the last few years.

9. In cutting across a thick steel plate 5 lb. of iron were actually removed from the cut. Theoretically, the amount of oxygen needed should in weight be 38 per cent of the steel removed. Assuming that in practice double this amount is required, what is the number of cubic feet of oxygen actually used?

10. In the electric-arc welding of mild steel state the various points of importance that must be noted in connection with the efficient working of the process.

EXAMINATION QUESTIONS 12

1. Give particulars of some of the dangerous conditions which may be set up through carelessness or ignoring the regulations which govern the use of acetylene.

2. Give sketches, and explain the various ways in which joints are prepared for welding.

3. Explain the difference between generated acetylene and dissolved acetylene. State the conditions under which it is an advantage to use either one or the other.

4. Give particulars of one kind of generator. State the precautions that should be taken in connection with the working of generators.

5. State the various ways in which the atmosphere either assists or retards the work of a welder.

6. Give a description of the cylinders that are used in connection with the storage of oxygen and acetylene. In what ways can they be misused?

7. Explain the construction of a hydraulic back-pressure valve. Why is it used?

8. Explain the difference between mild steel and cast iron. What kind of feed wires should be used to weld each of these?

9. Make a sketch showing the essential parts of a blow-pipe. Why does a blow-pipe sometimes back-fire?

10. A square frame is made of four pieces of angle iron welded at the mitred corners. Explain how you would prepare and weld the joints.

EXAMINATION QUESTIONS 13

1. State what you know of the regulations which govern welding installations. How may fire or explosions be brought about through neglect of these?

2. What are the defects which are usually found in welded joints? State clearly how these may be avoided.

3. Why is it that acetylene is such a valuable gas for welding purposes? State what you know of its properties.

4. State why it is so difficult to make a joint in mild steel plate to have the same physical properties as the plate itself. What is usually done to bring about the best results?

5. Make a sketch of a blow-pipe and state essential parts of the same. State the cause of back-fires and how these differ from flash-backs.

6. Explain how you would carry out a welding job in cast iron. What is the cause of hard spots and blow-holes sometimes found in welds?

7. Give particulars of the regulators used in connection with welding and cutting. How may these be damaged?

8. State what you consider to be the best method of preheating work and the fuel used in connection with the same. How can you judge the required temperatures?

9. If a large cast-iron pulley was broken through the rim and one spoke, explain how you would proceed to repair the same.

10. How does malleable cast iron differ from ordinary cast iron, and how would you proceed to make a weld or other form of joint in same?

EXAMINATION QUESTIONS 14

1. Explain why it is that some kinds of work can be done with greater advantage by arc-welding than with the oxy-acetylene process.

2. State the essential requirements for an electric-arc welding installation.

3. What kind of defects are usually found in connection with welds and what precautions should be taken to overcome these?

4. Show, by sketches, the various movements of the electrode that are used in welding, and state the object of them.

5. Explain the difference between using a long and a short arc. How do these affect the quality of the weld?

6. How would you prepare and weld a corroded part of a boiler shell seam, and how would you test same?

7. What are the obstacles met with in vertical and overhead welding? Explain how they are overcome?

8. Give a reasoned statement of the ways in which arc-welding can be used in various kinds of work instead of riveted connections.

9. Is there any advantage in hammering welds? State when it is advisable to hammer a weld and when not to do so.

10. State the dangers which may be present in carrying out any kind of welding in a boiler, tank, or other vessel, and particularly those that are applicable to electric welding.

EXAMINATION QUESTIONS 15

1. Clearly explain any possible cause of explosion that may occur in connection with welding installations, and how these may be avoided.

2. Give sketches of the various ways in which sheets or plates are prepared so as to give the best form of welded joint.

3. How much acetylene is usually generated per lb. of carbide used, and what are the causes of low production?

4. What proportion of oxygen to acetylene should be used in a well-constructed blow-pipe, and what are the disadvantages of using too much oxygen?

5. Give diagrammatic sketches explaining the types of generators that are in ordinary use.

6. Write down the list of things you would require to form a complete welding installation of the "low pressure system."

7. State some of the causes that go to the making of bad welds, and how these may be avoided.

8. After making a weld in a piece of mild steel explain how you would test same to determine its quality.

9. Explain how you would regulate the blow-pipe flame, and also state which part of this flame is used for welding.

10. State how you would proceed to fix up an installation for cutting purposes. Why is it necessary to use acetylene as well as oxygen in connection with this?

EXAMINATION QUESTIONS 16

1. Under what conditions is it possible to get a "back-fire" travelling along the acetylene pipes of an acetylene installation? What precautions are taken to avoid this?

2. Write a short statement giving particulars of the various methods of metal jointing that are in vogue, and state the advantages of oxy-acetylene welding against some of these.

3. Give particulars of what you would require for a complete welding installation for the use of ten blow-pipes.

4. State how acetylene is generated and the chemical action that takes place in its production from carbide. How much acetylene should 1 lb. of pure carbide produce?

5. Give brief particulars of some of the methods that are in use for the manufacturing of oxygen, and state what impurities are usually found in this gas.

6. Give clear sketches of two types of generators that are in use and explain their action.

7. Write out a clear statement giving particulars of the causes which produce bad welds. How may these be avoided?

8. Explain how you would weld a fracture in an aluminium crankcase. Why is it necessary to use a flux?

9. How does the composition of a mild steel welding rod affect the quality of the weld? Give the names of the injurious impurities.

10. If you had a mixed pile of cylinders, oxygen, hydrogen, coal gas, acetylene, and air, how would you proceed to sort them into their respective gases, and how would you be able to ascertain which gas was contained in each cylinder?

EXAMINATION QUESTIONS 17

1. Carefully compare the various methods of welding which are in vogue and state the advantages which metallic-arc welding has for certain classes of work.

2. State the diameter or gauges of electrodes that are usually used in connection with welding, and also give an idea of the voltage required and the amps used.

3. Arc welds in mild steel plate are sometimes found to be brittle. Give the causes of this defect and state how it may be overcome.

4. Write down what you know in connection with the

various kinds of electrodes that are used in connection with metallic-arc welding, stating the advantages and disadvantages of using bare electrodes, flux-coated electrodes, and lagged electrodes.

5. Give some particulars of the device which is used to control the current so as to make the voltage across the arc as constant as possible.

6. Certain types of boiler repair work can now be done by electric-arc welding, state what these are and also the advantage which arc welding has for this purpose over oxy-acetylene welding.

7. Explain how you would carry out a repair in connection with broken cast-iron work. What is the particular difficulty which has to be overcome in the electric welding of cast iron?

8. Metallic-arc welding is now being extensively used both in connection with mild steel plate work on tanks and other vessels, and also on structural work. Give particulars of some of this kind of work to which it is applicable.

9. State some of the ways in which electric-arc welds can be tested, both with regard to their strength and also their toughness.

10. Why is it that the intense light from the electric arc is dangerous? What precautions should be taken to avoid injury from this cause? Also state the necessary precautions which should be taken to avoid getting an electric shock.

EXAMINATION QUESTIONS 18

1. Certain precautions have to be taken in connection with the working of generators, handling of cylinders, etc. State what these are.

2. Make sketches and clearly explain the way to prepare and weld together two lengths of mild steel pipe to form a Tee-piece.

3. What is the difference between cast iron, wrought iron, and mild steel, and how does this difference affect their welding properties?

4. How much carbide would it take to generate 100 cub. ft. of acetylene?

5. Give sketches and explain clearly the working of any one kind of generator with which you are acquainted.

6. Give a full description of the cylinders that are used in connection with the storage of oxygen, hydrogen, and acetylene. State some of the ways in which they can be misused.

7. Why is it necessary to use a hydraulic back-pressure valve in connection with generated acetylene? State what precautions should be taken to keep it in proper working order.

8. Explain what methods are adopted for ensuring that welded joints shall be sound, and state the methods of testing which can be applied.

9. A cast-iron belt pulley is 3 ft. diameter and has six arms. If one of the arms was broken in two places, explain how you would proceed to repair same.

10. What is the difference between a cutting and a welding blow-pipe, and which of these uses the greatest proportion of oxygen?

EXAMINATION QUESTIONS 19

1. State what you know of the Regulations relating to the storage of carbide and the installing and use of welding plant. What dangers may be incurred through the neglect of these?

2. Show, by sketches, how you would saw up, prepare, and weld two pieces of mild steel pipe to form an obtuse elbow of 120 degrees. How are welded elbows tested?

3. State the difference between the physical and chemical properties of wrought iron, mild steel, and cast iron. In what ways have these to be taken into account when welding?

4. Give the composition of carbide; explain how it is made, and name the impurities it usually contains.

5. Make a sketch of a blow-pipe and state the essential parts of same. How may a blow-pipe get out of order, and state what causes it to sometimes back-fire?

6. There are several types of generators now in use; explain the principle in the working of two types, and their advantages and disadvantages.

7. Give diagrams showing the working of regulators and pressure gauges. Explain how these may become damaged and the dangers which may be set up by their misuse.

8. What are the difficulties usually met with in the welding of cast iron, and how are these overcome? What is the cause of hard spots and blow-holes in the welded portion?

9. Explain how you would make a longitudinal weld in a heavy piece of copper pipe.

10. The cubical capacity of a cylinder is $\frac{3}{4}$ of a cubic foot. How many cubic feet of oxygen at atmospheric pressure will it contain when the pressure gauge records 80 atmospheres?

EXAMINATION QUESTIONS 20

1. If you were in a works in which both the oxy-acetylene and electric-arc welding processes were used, upon what lines would you determine which class of work should be done by each process?

2. A large quantity of structural work is now being jointed by means of electric-arc welding; what advantage has this method of jointing over that of oxy-acetylene welding, riveting, or bolting?

3. In what ways does the composition of electrodes affect the quality of the resulting welded joint? Also, explain the functions of the fluxed and lagged coatings.

4. What effect has the varying length of arc upon the weld, and also the time taken in carrying out the work?

5. Cast-iron repairs are sometimes executed by the electric-arc process. Explain some of the methods adopted. What are the disadvantages of electric-arc welding of cast iron, and what efforts hav been made to overcome these?

6. Various methods have been suggested and some adopted for the testing of joints made by the electric-arc process in mild steel plates, so as to ensure that they shall have strength and toughness. State what you know of these methods.

7. Draw diagrams showing the various movements of the electrode which can be adopted in welding a joint. Give reasons why these movements are adopted to suit certain cases.

8. Explain how you would make a vertical weld on the side of a mild steel structure.

9. In which way are the cables connected to the work and electrode? Give reasons for your answer.

10. Explain what you know with regard to the Regulations which control electric-arc welding, in addition to which mention the various precautions which should be taken to avoid danger or injury from any cause.

EXAMINATION QUESTIONS 21

1. What precautions should be taken to prevent the water in generators freezing? If, however, it should happen to freeze, state how the operation of thawing could be safely done.

2. What precautions should be taken in the disposal of unspent carbide and of empty carbide drums to avoid the dangers of explosion?

3. Explain how acetylene is made from carbide of calcium, and state what are its usual impurities and how these can be eliminated.

4. What are the advantages and disadvantages, respectively, of the high- and low-pressure systems of welding?

5. Show by sketches how you would prepare round bars, flat bars, heavy plate, and thin sheet for welding.

6. What is the purpose of a hydraulic back-pressure valve, and what kind of attention should it receive previous to commencing to weld?

7. What kind of practical tests can you make to distinguish between wrought iron, mild steel, tool steel, and cast iron?

8. If welded joints have to be made in a mild steel vessel which is subjected to pressure, explain the precautions you would take to ensure that they were of the highest quality.

9. Make a sketch giving particulars of any type of blow-pipe, and state how its flame should be regulated for the welding of mild steel.

10. State what you know with regard to the cutting of metals by the use of the cutting blow-pipe. Does the quality of the oxygen affect the result?

EXAMINATION QUESTIONS 22

1. Acetylene in the free condition becomes explosive when under fairly high pressure. What is it that renders it safe when it is under high pressure in the dissolved condition in cylinders?

2. Explain the difference between what is known as a "harsh" flame and a "soft" flame. What is the cause of the two kinds of flame? Describe the results from each in their application to welding.

3. Give particulars of the various kinds of metal that can be cut with the oxygen cutting flame, and explain the reaction which takes place in the operation.

4. Why does aluminium welding create so many difficulties to the beginner? State what they are and how they can be overcome.

5. Write out a careful statement explaining the various points which have to be carefully noted in the welding of cast iron, and also in the welding of copper.

6. If you were in charge of a welding department state some of the methods you would adopt to secure the highest efficiency from the point of view of good welding work, and also the economical running of the welding department.

7. Explain the methods you would adopt to obtain the most efficient form of welded joints on vessels constructed from mild steel and which are to be used for pressure purposes.

8. Several explosions have taken place in connection with the repairing by welding of large tanks, gas holders, etc. Carefully explain the precautions which should be taken to avoid any form of danger in work of this description.

9. Give details of how you would repair a broken malleable cast spanner so as to ensure a good strong joint.

10. Give particulars of the various kinds of blow-pipes which are used in connection with low-pressure generated acetylene and also with dissolved acetylene. In what ways do blow-pipes get out of order?

EXAMINATION QUESTIONS 23

1. Discussions are often taking place as to which is the better process, gas welding, or electric arc welding. State your opinion on the subject, giving reasons for same.

2. Electric arc welding is now very largely being used for jointing tanks or vessels which are subjected to low internal pressure. What form of test is usually applied to tanks of this description?

3. Show by sketches the various ways in which joints are prepared in mild steel work and also for repairs in connection with cast-iron breakages.

4. What part does the atmosphere play in connection with the making of arc welds? What methods are adopted to overcome any defects which may be set up by the oxygen or nitrogen of the atmosphere coming into contact with the metal as it passes through the arc?

5. What percentage efficiency do you expect to obtain in

the welding of a plate-iron joint? How is it possible to make a joint as strong as the surrounding plate?

6. Various kinds of wires and coatings for same are used as electrodes in arc welding. Give particulars of some of these and explain the uses of the various electrodes.

7. Dummy "rivets" are sometimes put in by electric-arc welding where plates are not subjected to much bend or stress. Make sketches showing how these "rivets" are run in.

8. Write out a list of all the things you would require for a complete welding equipment for a single operator.

9. Draw a diagram of the wiring for a simple welding plant, show how the current is automatically regulated to give a suitable arc.

10. Explain how the quality of the deposit varies with the variations in intensity of the heat of the arc.

EXAMINATION QUESTIONS 24

1. So as to ensure safe working of a generator, state the main things that require attention or careful inspection.

2. Which is the purest kind of acetylene, that from a generator or from a cylinder? What are the advantages of using the purest form of acetylene?

3. As several kinds of gases are now compressed into cylinders, it is essential that an operator should be able to distinguish between the various kinds of cylinders. What is the difference between cylinders containing oxygen, hydrogen, air, coal gas, and acetylene?

4. What are the maximum pressures to which acetylene and oxygen are usually compressed in cylinders? State how it is possible to tell the quantity of these gases in cylinders which have been partly used?

5. State how you would adjust the flame of a blow-pipe to give the best results when welding mild steel plate.

6. Two pieces of $\frac{1}{4}$ in. plate have to be welded together at right angles. State any kind of preparation of the plate that may be necessary, and also how you would carry out the work.

7. Two lengths of 3-in. mild steel pipe have to be joined up into one length. State how you would prepare the ends of the pipes, and also how you would carry out the welding.

8. Various defects are sometimes found in welds through careless workmanship. State what some of these are, and how they can be avoided.

9. State what kinds of tests you would make to find out the quality of your own workmanship in the welding of wrought iron and mild steel.

10. The cutting blow-pipe is now used to perform a variety of operations. State what some of these are, and the advantages of the use of the cutting blow-pipe.

EXAMINATION QUESTIONS 25

1. If you had charge of an acetylene welding installation where both generated and dissolved acetylene were used, state the various precautions you would take to ensure the safe and economical working of the plant.

2. There are various types of generators in use. Give a reasoned statement as to why you would prefer any one type more than another.

3. In carrying out certain kinds of welding jobs, the method of pre-heating is adopted. State clearly some of the advantages of pre-heating work.

4. Joint preparation is an integral part of good welding work. Give some illustrations of the necessary preparation in one or two jobs with which you have been acquainted.

5. In what way does the atmosphere affect welding conditions? Give illustrations of its advantages to the welder, and also its disadvantages; and in the latter case, how are these overcome?

6. Cast-iron repairs are now an important part of the welder's work. Explain how you would repair a cracked motor-car cylinder, or other important repair work with which you are acquainted.

7. What are the disadvantages which have to be overcome in connection with the welding of copper? How are these now being dealt with?

8. Does the composition of the feed wire or the condition of its surface affect the quality of the resulting weld? State what you know of this from your own experience.

9. Rustless steel and "Staybrite" are now being used and welded in connection with the fabrication, for various purposes, of pans, cylinders, etc. How should welding for this class of work be carried out?

10. Expansion and contraction through heating and cooling are a very real difficulty in connection with certain classes of work. State what measures are taken to overcome these difficulties.

EXAMINATION QUESTIONS 26

1. In addition to the generator there are several other things required for an efficient electric welding set. State what these are and the purpose they serve.

2. Write out a list of the kinds of work which can be efficiently and economically welded by the electric-arc process.

3. Why is it that for tank work and long plate seams the electric-arc system of welding is more economical than acetylene welding?

4. In connection with plate work make sketches of the various kinds of joints that are being used and state their application.

5. Feed wires for electrodes are of many kinds and have many forms of coatings. State what you know of the use of these and of their advantages and disadvantages.

6. Electric-arc welding is sometimes used in connection with cast-iron repairs. Give a description and make sketches of the kind of work for which it is suitable.

7. There is now growing up a considerable business in the fabrication of what is known as "weldings," these being plate iron articles which take the place of castings. Give a description of one or two welded samples of this class of work.

8. Make sketches showing two or three of the electrode movements that are used in connection with welding. Which of these do you consider gives the best result?

9. What are the precautions which have to be taken in connection with electric-arc welding to avoid electric shocks and dangers to eyes and skin?

10. State what you know regarding the new atomic hydrogen electric arc welding process. What are its particular advantages? Why is it not likely to come into general use?

EXAMINATION QUESTIONS 27

1. In starting up a new generator what precautions would you take so as to ensure that air does not get mixed with the acetylene which passes to the blow-pipe?

2. Make a sketch of any kind of generator with which you are acquainted and clearly explain its working.

3. In carrying out a job 80 cub. ft. of acetylene is required. How many pounds of carbide would be required to generate this amount of gas?

4. In welding operations acetylene is taken either from a generator or from a cylinder. State the conditions under which it is advisable to use either one or the other.

5. Make sketches of three different forms of joints which are used in connection with acetylene welding.

6. Does the quality of the feed wire or the condition of its surface in any way affect the quality of the resulting weld? If so, state the disadvantages of using unsuitable wire.

7. Sometimes a mild explosion is set up by the use of an unsuitable hydraulic back pressure valve or the neglect in the use of a correct valve. Make sketches of a suitable valve and explain the kind of regular attention it should receive.

8. A piece of 2 in. diameter pipe is to be sawn and jointed to form an obtuse angle of 135 degrees. Show by sketches how you would saw the pipe and arrange the joint for welding.

9. Explain how you would make a joint in mild steel plate so that it would not only be strong but would also have maximum toughness.

10. Make sketch of both the welding and cutting blow-pipes. In what ways do they differ?

EXAMINATION QUESTIONS 28

1. At various times explosions have taken place in connection with the use of acetylene or with vessels which have been used for the storage of explosive gases or vapours. Explain the cause of these explosions and how they may have been avoided.

2. Give the composition of carbide of calcium and of acetylene, and explain the reactions which take place when the latter is made from the former.

3. What precautions should be taken in connection with the housing of generators, the storage of carbide, and the use of same? State the dangers which may be set by the neglect of proper precautions.

4. Make a sketch of the flame of the oxy-acetylene blowpipe, and explain the reactions which take place in the flame. What are the disadvantages in using an oxydizing flame or a carbonizing flame?

5. If you had to test a set of blow-pipes to pick out the one which you considered the best, state the method you would follow and give your reasons for the choice of any one blow-pipe.

6. What is the difference between wrought iron, mild steel, and tool steel? How can you tell one from the other? What defects are found in the weld when high phosphorus mild steel is used either in the plate or feed wire?

7. State some of the defects which are to be found in welds, and explain how they may be avoided so as to obtain the most efficient form of joint.

8. If you had to weld a vessel made of mild steel which had to stand a considerable pressure, show by sketches how you could strengthen the joint by some form of reinforcement.

9. Aluminium and aluminium alloys can now be welded with a good deal of certainty. Explain how you would carry out a job in these two materials.

10. How does the quantity of oxygen in a cylinder vary with its change of pressure? If a cylinder has a capacity of one-half of a cubit foot, how many cubic feet of oxygen at atmospheric pressure will it contain when the pressure gauge records 30 atmospheres?

EXAMINATION QUESTIONS 29

1. Give a description of some classes of work which can be done with arc welding better than with acetylene welding. State what the advantages are.

2. Give a description of the various methods of resistance welding, and describe how these differ from arc welding. What kind of work is usually done by resistance welding?

3. Describe how worn shaft journals are built up, and state what precautions have to be taken to prevent the shaft from distortion.

4. Which gives the best deposit, a long or short arc? What defects in the work are set up when too much current is used?

5. What effect has the "polarity" on the electrode and the work to be welded? Why is it advisable to have the welding "lead" as short as possible?

6. What precautions is it necessary to take to avoid defects in welds? In what way does the kind of electrode, size of Vee, and the cleaning of the parts to be welded affect the deposit?

7. State what precautions should be taken against electric

shock, current leakage, and the protection of the eyes and skin?

8. Describe the ways in which copper can be used to assist in the building up of parts on rather difficult jobs.

9. Why is it advisable to make several runs with different sized electrodes when a deep Vee is being filled?

10. In welding cast iron sometimes a very hard line or area shows after the weld is made. What is the composition of this area and what means should be adopted to avoid its formation?

EXAMINATION QUESTIONS 30

1. Several explosions have occurred in the careless handling or using of the gases employed in connection with welding. State what precautions should be taken to avoid accidents.

2. If the water in a generator becomes frozen during the night through being in an exposed position, state what you would do before proceeding to start generating acetylene.

3. How many cubic feet of oxygen would be required in connection with the use of 60 cub. ft. of acetylene in carrying out a welding job, assuming that the two gases are used in the most economical manner?

4. Briefly describe the action of any type of acetylene generator with which you are acquainted. At what pressure is it usual to deliver the gas for welding?

5. The deposited metal in a welded V joint in mild steel is sometimes very hard, and readily breaks on bending the plate or bar. What is the cause of the hardness and how can it be avoided?

6. The bottom plate of a cylindrical tank is to be welded to the body. Show by sketches the various types of joints which can be used for the purpose.

7. Explain how cylinders, which contain respectively oxygen, air, acetylene, coal gas, and hydrogen, can be distinguished one from the other.

8. Explain how you would make a welded T-pipe joint by connecting a 2-in. diameter pipe on to a 3-in. diameter pipe. Show by sketches how you would prepare the pipes before welding.

9. Explain how you would proceed to test a specimen weld which you had made in either wrought iron or mild steel.

10. Describe metal cutting by oxygen and the apparatus used for this purpose. How does oxygen "cut" the metal?

EXAMINATION QUESTIONS 31

1. State the various ways in which metals can be jointed, and give reasons why oxy-acetylene welding, for some purposes, has advantages over all the other methods of jointing.

2. State the relative advantages and disadvantages of generating acetylene by the "water to carbide" and "carbide to water" methods. Give particulars, with sketches, of any type of generator with which you are familiar.

3. The preparation of work plays an important part in good welding practice. Give some particulars, with sketches, of the necessary preparation in one or two jobs with which you have been acquainted.

4. Give the composition of carbide of calcium and state the impurities it usually contains, and how these affect the quality of the acetylene. What methods are adopted to remove as far as possible, the impurities in acetylene?

5. What is the difference between wrought iron, cast iron, and mild steel? How do these differences show up in actual welding practice? State why ferro-silicon rod is used in welding cast iron.

6. What kinds of tests could be applied to the welds which had been made on a cylindrical tank? Considering the difficulties of testing welds in position, state the precautions which should be taken to ensure that welds are properly made.

7. State the various methods which are adopted to overcome the defects which may be set up in various jobs through expansion and contraction of metals.

8. Seeing that the melting point of copper is lower than that of mild steel, why is the former metal so much more difficult to weld than the latter? What methods are now adopted to ensure good welds in copper plate?

9. Under what conditions is it possible to get a "back-fire" travelling along the acetylene pipes which are connected to a generator? State all the precautions which should be taken to avoid this danger.

10. Explain clearly the chemical action which takes place in cutting mild steel by the oxy-acetylene blow-pipe. Why is it so difficult, and in some cases impossible, to "cut" other metals by this process?

EXAMINATION QUESTIONS 32

1. Electric welding is now coming into use to displace riveting and also castings. Give particulars of some of these two classes of work for which electric welding is suitable.

2. State the essential requirements for a one operator electric-arc welding installation for either D.C. or A.C.

3. Show by sketches the various kinds of joints which can be made in both thin and thick plate work by arc welding.

4. To what thicknesses of plate should a 10-gauge electrode be applied? About what amperage will give the best results for this size electrode? What are the disadvantages of using a too high or too low current?

5. There are certain special kinds of electric-arc welding which are used in connection with repetition work or where a tough deposit is required. State what you know of these methods.

6. How does the length of the arc affect the quality of the deposit? State the precautions which should be taken to give the most solid and ductile deposit in joints.

7. Why is there more danger from shock in the use of A.C. than from D.C.? The Home Office lay down certain rules and regulations for the guidance of welders; state what you know of these.

8. What class of work is it possible to do with bare electrodes? Give some particulars of coated or lagged electrodes which are used and the particular purposes to which they are applied.

9. To ensure good welding on important work, test-pieces are sometimes first made and tested to destruction. Explain how these test-pieces should be made and tested. What would constitute good and bad specimens?

10. Where it is possible is there any advantage in annealing a weld or the vessel of which it forms a part? What defects may be set up in mild steel plate through wrong methods of heat treating the steel?

The following typical examination papers of the City Technic College, Liverpool, and the City and Guilds of London Institu are reproduced by permission.

City Technical College, Liverpool
OXY-ACETYLENE WELDING
First Year—Theory

1. If the lid of a drum containing carbide was removed an its contents exposed to the atmosphere for some time, wha would happen to the carbide? If the drum happened to be i an enclosed space would there be any danger of an explosion

2. At what pressure is acetylene usually supplied from generator? What are the disadvantages, in welding, of usin the acetylene at too low a pressure?

3. There are several ways in which water and carbide ar brought together to generate acetylene. Show by the aid o sketches two of these methods.

4. Explain how acetylene is stored in cylinders, and the advantages and disadvantages of having it in this form. State the various ways in which acetylene and oxygen cylinders differ.

5. Make a sketch of any kind of blowpipe with which yo are familiar, and explain how the pressures of the gases ar controlled so as to produce a flame which will give the best welding results.

6. If you had to make a welded joint on mild steel plates ¼ in. thick, state how you would prepare the edges of the plates, and the methods you would adopt to obtain a strong tough deposit.

7. It is sometimes said "That the atmosphere is both a friend and an enemy of the welder." Explain what is meant by this statement.

8. Feed wires used in welding vary very much in quality and in the kinds of joints they produce. If you had three samples of wire, explain how you would test these so as to pick out the one which would give the best results in practice.

9. Explain how you would prepare the ends of two pieces of 2½ in. diameter pipe and weld them together so as to keep the centre lines in alignment, and at the same time obtain a tough and tight joint.

10. If you were asked to prepare a number of test specimens to show your ability as a welder of mild steel or wrought iron, explain the kind of specimens you would prepare and the methods you would adopt to prove their strength and toughness.

Oxy-Acetylene Welding

Second Year—Theory

1. Give particulars of the regulations regarding the storage and use of carbide of calcium. State some of the precautions which should be taken to guard against any possibility of explosion or fire in connection with the generation and use of acetylene.

2. Give the composition of acetylene, and name some of the impurities which are usually found in the gas, and state how they come to be present. How is acetylene purified?

3. When is it advisable to use D.A. in preference to acetylene from a generator? State the usual pressure of generated acetylene and also the maximum pressure to which dissolved acetylene is compressed.

4. How many cubic feet of oxygen at atmospheric pressure does it take to weigh 1 lb.? How many cubic feet does a cylinder usually contain and what is the maximum pressure of the gas? Is the pressure of oxygen in a cylinder affected by changes of temperature in the atmosphere, if so, in what way?

5. Does the purity of oxygen have any influence on welding and cutting, both from the point of view of quality of work and time in carrying out the operation?

6. State briefly how mild steel is manufactured, and explain the nature of some of the impurities which get into the steel and their effect in welding both in plates and feed wire.

7. Explain some of the precautions which have to be taken to ensure the obtaining of solid welds in cast iron. Which kinds of cast iron are the most difficult to weld, and in some cases impossible?

8. Explain how you would make a weld in aluminium sheet or plate. After having made a test piece in aluminium sheet, how would you proceed to test it for both strength and toughness?

9. A 2 in. diameter pipe is to be jointed to a 3 in. diameter pipe to form an oblique tee piece having an angle of 135 degrees. Explain how you would carry out the preparation of the joint and the welding of same. If you made a preliminary sample, how would you test it to show the quality of the deposit?

10. What is meant by the terms "normalizing" and "annealing"? How are these processes carried out in connection with both mild steel and copper?

Electric Arc Welding

Theory

1. State the precautions which should be taken to avoid risk of electric shock, and also injury to the eyes and skin.

2. What striking voltage is required in direct current arc welding? Also what voltages is it necessary to have to maintain the arc in using the various kinds of electrodes?

3. Compare the D.C. and A.C. systems of welding, and state the particular advantages and disadvantages of each system.

4. Make a sketch showing how you would prepare the edges of $\frac{3}{8}$ in. plate for a single vee-butt joint. Also make a sketch showing the preparation of the edges of 1 in. plates to form a double vee-butt joint. What size of electrodes would you use in welding these two kinds of joints?

5. Show by sketches how you would join together two plates at right angles to form a corner, the weld being on the outside. How would you test a specimen joint of this description?

6. Explain how the quality of a weld deposit may be affected by the varying conditions set up in welding—such as the skill of the welder, type of electrode, length of arc, current, etc.

7. What is meant by the terms "normalizing" and "annealing." When is it an advantage to carry out these processes in connection with welding?

8. In some kinds of pressure vessels it is permissible to weld straps across the joints to give additional strength or stiffness. Make sketches of the kind of straps so used and show their positions on a joint.

9. Certain changes take place in the electrode metal as it passes through the arc. State what these changes are in the case of mild steel electrodes.

10. Under suitable conditions cast iron can be welded with the electric arc. What are the usual defects found in cast iron so welded and what means can be taken to overcome these?

City and Guilds of London Institute

PRINCIPLES OF ELECTRIC ARC AND OXY-ACETYLENE WELDING

General Paper

Section 1

1. Describe any experiments which show that the atmosphere is a mixture of oxygen and nitrogen.

2. What do you understand by "oxidation and reduction"? Give examples of each in welding practice.

3. State (*a*) The effect produced by heating (i) iron, (ii) copper, and (iii) aluminium to redness in air; and

(*b*) The effect of hydrogen on iron oxide, copper oxide, and aluminium oxide at the same temperature as in (*a*).

4. Distinguish carefully between the temperature of a piece of steel and the quantity of heat in it. In what units is each measured?

5. Explain the term "coefficient of expansion."

A block of iron occupies a volume of 5 cub. feet at 100° C. If the coefficient of linear expansion of iron be 0·000012, calculate the volume of the block at 0° C

6. Describe what occurs when the end of a steel poker is placed in a fire and left there until the whole poker reaches a steady state of temperature. What differences would you expect to observe, if the poker were made of copper instead of steel?

7. Explain the terms "stress" and "strain." Illustrate your answer by reference to three simple forms of stress, and show how the resultant strain may be measured in any one case.

8. How would you determine the melting point of a solid by plotting its cooling curve? Explain the theory underlying the determination.

9. Draw to scale, with your ruler, a plan and side elevation of the welding on the flat of two prepared mild steel plates with full chamfer. (Size of plates: 6 in. by 3 in. by $\frac{1}{2}$ in.)

Section 2

10. Describe three different systems of welding. Indicate a practical application of each.

11. The cooling curve of a piece of mild steel previously heated to 900° C. shows three critical temperatures. What is the nature of the changes at these temperatures?

12. You are informed that a steel specimen is in the austenitic condition. What inferences can you draw from this information as regards the probable composition and the previous heat treatment of the specimen? Give reasons for your answer.

13. It has been said that the oxy-acetylene process has several advantages over the electric arc process in the welding of cast iron. Do you believe this to be true and, if so, what are your reasons?

14. Discuss the structure of a steel in the "as cast" condition. Why does a mild steel weld rarely show an "as cast" pattern?

15. Compare the physical properties and the structure of a brass containing 40 per cent of zinc with one containing 30 per cent of zinc.

16. Explain or define the following: (*a*) Solid Solution; (*b*) Pearlite; (*c*) Brinell Number; (*d*) Burnt Steel.

17. The following elements may be present in weld metal: Manganese, nitrogen, hydrogen, nickel and sulphur. What effects, beneficial or otherwise, do they have?

18. Show, with the aid of sketches, how you would prepare an all-weld tensile test piece.

Section A. Electric Arc Welding

1. Describe briefly the composition and main properties of *five only* of the following, indicating which types of electrodes should be used, and any precautions that should be taken in welding—

(i) Stainless steel of 18/8 type;
(ii) malleable iron castings;
(iii) 12–14 per cent manganese steel;
(iv) high speed steel for lathe tool;
(v) boiler plate;
(vi) 1½ per cent manganese steel or chrome steel;
(vii) copper;
(viii) aluminium;
(ix) monel metal.

2. Describe, by the aid of sketches, how you would weld *three* of the following in the case of mild steel—

(*a*) Double vee butt joint in ¾ in. thick plate;
(*b*) corner butt joint in ½ in. thick plate;
(*c*) butt joint between two pieces of 1 in. diameter shafting;
(*d*) joggled over lap joint in ½ in. plate;
(*e*) vertical butt joint between two pieces of ½ in. thick plate.

Indicate in each case the size of electrodes and the amperage required.

3. Describe the type, and the separate units, of the welding

plant that you would recommend for installation at a works in each of the following cases:

Power supply.	*Equipment for*—
(*a*) 400 volts D.C. . . .	One welder.
(*b*) 400 volts D.C. . . .	Four welders.
(*c*) 400 volts A.C. 3-phase . .	Two welders.

Give a diagram of the external connections for each plant.

4. Describe any advantages that accrue from welding with flux-covered electrodes as compared with welding with bare wire, and compare the properties of the weld metals obtained. Give the composition of any suitable flux covering.

5. Describe, by the aid of sketches, how you would—

(*a*) Reinforce the surface of a 0·3 per cent carbon steel axle 3 in. diameter to give a reinforcement $\frac{1}{8}$ in. thick and 6 in. long after machining;

(*b*) reinforce the worn head of a carbon steel rail;

(*c*) repair a crack in a cast iron casting $\frac{1}{2}$ in. thick.

Indicate type and size of electrodes and amperage to be used.

6. What is meant by penetration in the case of—

(*a*) Reinforcing a steel plate;

(*b*) making a fillet weld in a lap joint?

Indicate by sketches the extent to which penetration is desirable.

7. Why does distortion of the work occur during and after welding? Indicate how you would weld the following to prevent distortion in the welded work—

(*a*) A butt joint 10 ft. in length between two pieces of mild steel plate $\frac{3}{8}$ in. thick;

(*b*) A longitudinal butt joint in a pipe formed by rolling a piece of mild steel plate $\frac{1}{16}$ in. thick into a tube 2 ft. long by 8 in. diameter.

Section B.—Oxy-Acetylene Welding

1. Give particulars of—

(*a*) Low pressure welding equipment.

(*b*) High pressure welding equipment.

What are the possible dangers with each type, and in what ways is safety assured?

2. What is the principle of metal cutting with the blowpipe?

Make a diagrammatic sketch showing the difference between a welding blowpipe and a cutting blowpipe. Can all metals be cut with the cutting blowpipe? Give reasons for your answer.

3. What are the characteristics of a good weld in—

(a) Mild Steel,
(b) Copper,
(c) Aluminium?

If no testing machines were available, to what methods would you resort in order to test the quality of the weld?

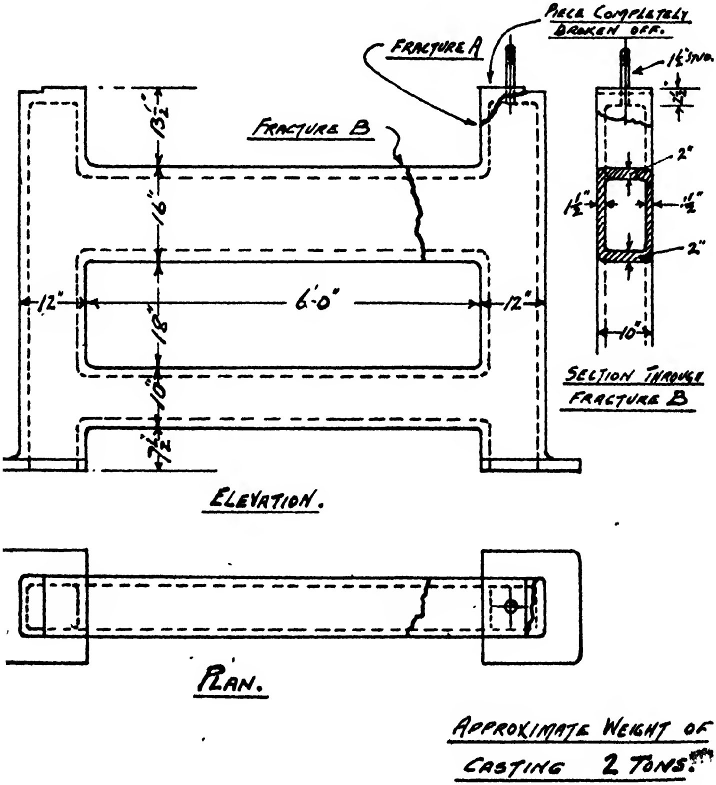
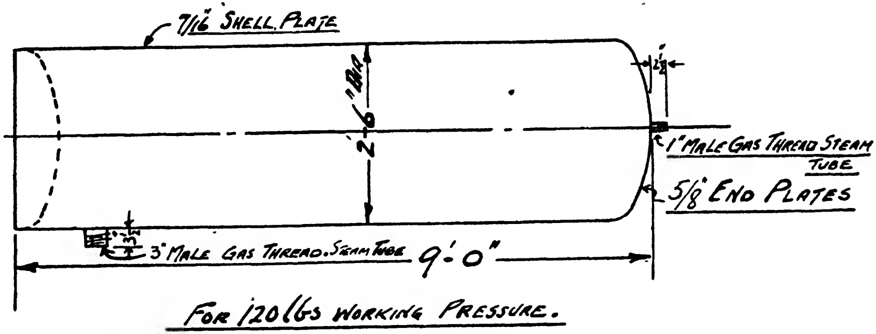


Fig. 152



7/16" SHELL PLATE
2'-6" DIA
1" MALE GAS THREAD STEAM TUBE
5/8" END PLATES
3" MALE GAS THREAD. STEAM TUBE
9'-0"
FOR 120 LBS WORKING PRESSURE.

FIG. 153

Describe the appearance of the most frequently found defects in each case.

4. The iron casting shown in Fig. 152 is fractured at A and B. State the plant and tackle that you consider necessary to weld the fractures and describe in detail how you would proceed.

5. Describe the "Leftward" (forward) and "Rightward" (backward) technique in welding. Sketch the relative positions of the deposited metal, blowpipe and filler rod in each case. State what preparation, if any, is desirable in each case and for what thicknesses of mild steel each method is more suitable.

6. Give a list of five important metals that can be welded by the Oxy-Acetylene process. State, giving reasons in each case, whether a filler rod of the same chemical composition as the parent metal is satisfactory. State whether a flux is necessary and the purpose of the flux.

7. What is meant by

(*a*) Hard facing,
(*b*) Bronze welding?

Give two instances of purposes for which each is beneficial and state why.

8. Show where you would make welded joints in the vessel indicated in Fig. 153. Assume that the largest available plates are 4 ft. 6 in. by 10 ft. Sketch the type of preparation and weld at each joint, and state in detail how you would proceed with the welding of each joint.

9. Name three commonly used metals that can be satisfactorily welded both vertically and overhead. Give particulars of the procedure necessary for (*a*) vertical and (*b*) overhead welding.

APPENDIX

The Progress of Welding

Its Applications. There is now hardly an industry of any description in which some form of welding does not play an important part, either in the processes of manufacture or fabrication, or in connection with the building of the required machinery or plant, the repairing of same, and also the construction of the buildings. The joints in the steel-work of large structures are now being made by welding processes, and also a large amount of the jointing in connection with shipbuilding is made in this way. Also certain forms of pressure vessels are being completely welded with success. Very great strides have been made in the fabrication of a great number of articles out of plate and bar which were formerly made out of cast iron. Considerable advance has been made both in the construction and repair of bridges and other kinds of railway work. There is, in addition, an improvement in the quality and quantity of work which is now being done in connection with non-ferrous metals and alloys.

Acetylene Generators are increasingly being improved with a view to giving a purer supply of acetylene at a constant pressure and with complete safety.

Dissolved Acetylene is now being used in very much larger quantities, and at the same time being sent out in cylinders with the greatest degree of safety. On account of the portability of the cylinders, the purity of the gas, and the ease with which the pressure can be maintained constant at the blowpipe, acetylene in this form is found to be most convenient for important classes of work.

Oxygen is now being supplied with a high degree of purity,

thus insuring economy of working together with a certainty of producing high class work.

Feed Wire for all classes of gas welding can now be obtained which will give the very best results in practice. This is due to the improved qualities of steel, copper, and alloys now being made, and also to the excellent research work which has been carried out by the metallurgists and chemists of the companies who market the supplies.

Blowpipes are increasingly being improved in the direction of giving the best form of flame together with the most economical use of the gases. The *Twin Jet* blowpipe is now being used for heavy kinds of work, thus speeding up production and producing a better type of joint due to the preheating properties of the advance jet.

Backward or Rightward, instead of forward or leftward, method of welding is increasingly being used, as there can be no doubt that this method of movement gives the soundest kind of joint, and also uses the gases in the most economical manner.

Generators and Transformers for electric arc welding have now been so improved that a steady type of arc can be set up which gives a weld deposit of sound solid metal.

Shielded Arc and Atomic Hydrogen methods of welding are making great strides in the direction of producing weld deposits of great purity and toughness.

Electrodes. Great improvements in electrodes have been made due to the improved qualities of the steel core wire, the composition of the coating and the methods of applying it to the wire.

Heat Treatment is now being applied to welded joints and welded vessels with a view to relieving the residual stresses in metal. Also heat treatment is being successfully applied to welded stainless steel vessels to produce a uniform grain structure which will obviate "decay" which sometimes takes place in the plate just outside the welded joint.

Welding Instruction. Courses of training for welders are

being increasingly started. Several of the larger firms who supply welding plant and materials hold classes for intensive instruction, and a few companies who apply welding extensively in the formation of their products run their own training schools. Many evening classes are held at technical schools and colleges. One of the largest of the welding schools is that connected with the City Technical College, Liverpool, the buildings of this being specially constructed for the purpose. A view of one end of the oxy-acetylene welding shop is shown in Fig. 154, and an instructor giving a demonstration in electric welding in Fig. 155. This training school has accommodation for ten oxy-acetylene welders and six electric welders, who can all be working at one and the same time.

Examinations. These are now being held both by the City and Guilds of London Institute and other institutions. There seems to be some confusion as to the kind of syllabus which should be drawn up and the type of examination paper that should be set. Welders, generally, can be put into one or other of two categories. In one category is the ordinary working welder, who may be on routine work or general repair jobs, and the other category is composed of technically trained men connected with the metal or engineering trades. The latter class are those who become foremen, inspectors, designers, instructors, or technical representatives. Those of the latter category have no need to become extremely skilled welders in all classes of work and kinds of welding, as this requires a fairly long and varied workshop experience. The training for this class of man cannot be too wide, as he will have to investigate all kinds of problems which require some knowledge of physics, chemistry, metallurgy, and general engineering science. It will thus be seen that an examination for this second category must be of quite a different character to one set for the first. In the City and Guilds of London Institute examination it will be noticed that the candidate must take

Fig. 154.—Acetylene Welding at the City Technical College, Liverpool

three-operator set, one welding point being connected to each phase of the M.W.P. Static Transformer. A reactance coil is used for each welding circuit, the current adjustment being made by sliding the core into the desired position. The range of each coil is from 50 to 200 amperes.

A Quasi-Arc lay-out for A.C. welding is shown in Fig. 173. In this the wiring can be arranged for one or more regulators according to the capacity of the transformer and the number of operators required to be at work.

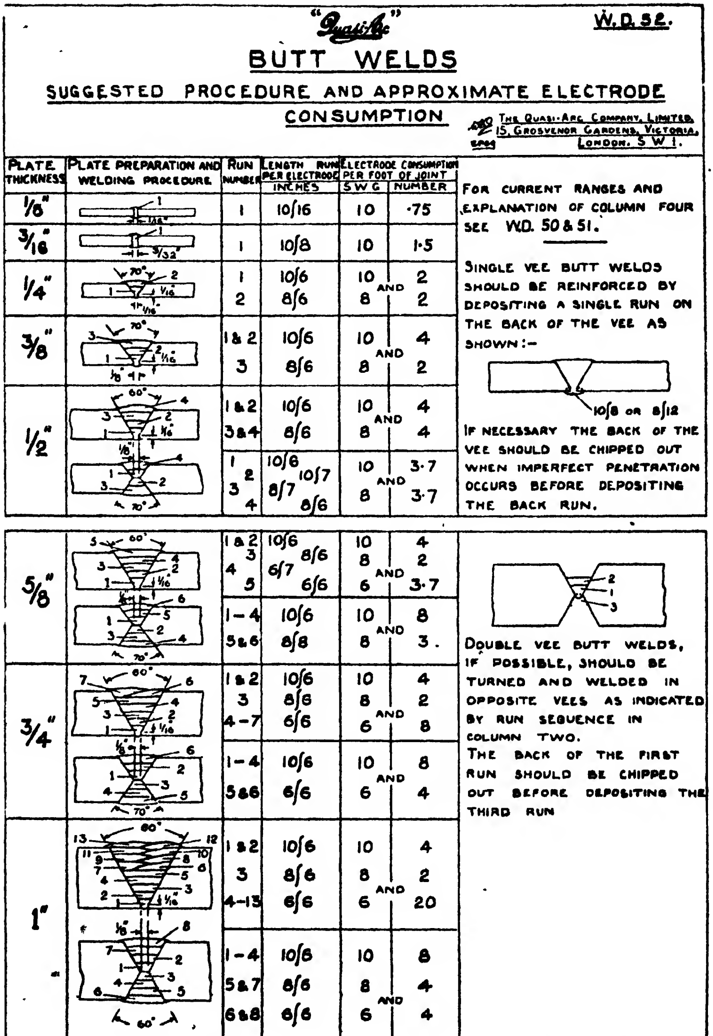
Fig. 174 shows a double-operator portable static transformer welding plant, suitable for welders employed on light to medium work using small gauge electrodes up to No. 10 S.W.G. It consists of two units each having a current range of 29 to 100 amperes in six stops.

Fig. 175 shows the railway type of petrol engine-driven set. There are many of these sets in operation, also some which are coupled to Diesel engines. This type of welding set can also be detached from its bed and used as a portable welding plant.

Welding Data

The tables shown in Figs. 176, 177, and 178, published by permission of the Quasi-Arc Co. Ltd., give a suggested method of procedure and approximate electrode consumption for the particular kinds of joints shown. It must, however, be borne in mind that many applications require special treatment; also that local working conditions may render permissible or desirable both modifications of the procedure suggested, and either a decrease or increase in the size of the electrodes applied.

Standard Electrodes. The British Standards Institution has recently published specifications for electrodes, which give the composition of the steel wire and some of the physical properties that the coatings should possess. In view of the extraordinary variety of electrodes which are sold and the claims which are made for them, it is not an



"Quasi-Arc" W.D. 52.

BUTT WELDS

SUGGESTED PROCEDURE AND APPROXIMATE ELECTRODE CONSUMPTION

The Quasi-Arc Company, Limited, 15, Grosvenor Gardens, Victoria, London. S.W.1.

Plate Thickness	Plate Preparation and Welding Procedure	Run Number	Length Run per Electrode Inches	Electrode Consumption per Foot of Joint S.W.G.	Number
1/8"		1	10/16	10	·75
3/16"		1	10/8	10	1·5
1/4"		1 2	10/6 8/6	10 and 8	2 2
3/8"		1 & 2 3	10/6 8/6	10 and 8	4 2
1/2"		1 & 2 3 & 4	10/6 8/6	10 and 8	4 4
		1, 2 3, 4	10/6, 10/7 8/7, 8/6	10 and 8	3·7 3·7
5/8"		1 & 2 3 4 5	10/6 8/6 6/7 6/6	10 8 and 6	4 2 3·7
		1–4 5 & 6	10/6 8/8	10 and 8	8 3.
3/4"		1 & 2 3 4–7	10/6 8/6 6/6	10 8 and 6	4 2 8
		1–4 5 & 6	10/6 6/6	10 and 6	8 4
1"		1 & 2 3 4–13	10/6 8/6 6/6	10 8 and 6	4 2 20
		1–4 5 & 7 6 & 8	10/6 8/6 6/6	10 8 and 6	8 4 4

For current ranges and explanation of column four see W.D. 50 & 51.

Single vee butt welds should be reinforced by depositing a single run on the back of the vee as shown:—

10/8 or 8/12

If necessary the back of the vee should be chipped out when imperfect penetration occurs before depositing the back run.

Double vee butt welds, if possible, should be turned and welded in opposite vees as indicated by run sequence in column two. The back of the first run should be chipped out before depositing the third run.

Fig. 176.—Table of Welding Data for Butt Joints

(The Quasi-Arc Co.)

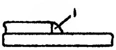
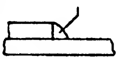
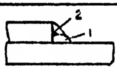
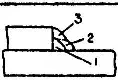
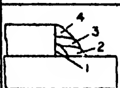
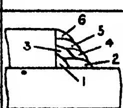
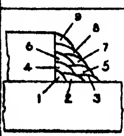
"Quasi-Arc"

W. D. 51.

LAP WELDS——FULL FILLETS

SUGGESTED PROCEDURE AND APPROXIMATE ELECTRODE CONSUMPTION

The Quasi-Arc Company, Limited, 15 Grosvenor Gardens, Victoria, London. S.W.1

PLATE THICKNESS	WELDING POSITION AND PROCEDURE	RUN NUMBER	LENGTH OF RUN PER ELECTRODE INCHES	ELECTRODE CONSUMPTION PER FOOT OF FILLET S.W.G.		NUMBER
1/16"		1	14/6	14		2
1/8"		1	12/10 OR 10/14	12 10	OR	1·2 ·85
3/16"		1	10/8	10		1·5
1/4"		1	10/6 OR 8/9	10 8	OR	2 1·33
5/16"		1 & 2	10/7	10		3·5
3/8"		1 2 & 3	8/9 OR 10/6 8/10	8 10 8	OR AND	3·75 2 2·4
1/2"		1 2 3 4	8/9 OR 10/6 8/7 8/6 8/8	8 10 8	OR AND	6·5 2 5·2
5/8"		1 2 3 & 4 5 6	8/9 OR 10/6 8/6 8/8 8/7 8/8	8 10 8	OR AND	8·5 2 8·2
3/4"		1 2 & 3 4 – 7 8 9	8/9 OR 10/6 8/9 8/7 8/6 8/8	8 10 8	OR AND	13 2 11·7

THE CURRENT RANGE REQUIRED FOR EACH GAUGE OF 'QUASI-ARC' ELECTRODE IS AS FOLLOWS :—

No.	16	S.W.G.	20 - 35 AMPS
"	14	"	35 - 45 "
"	12	"	65 - 85 "
"	10	"	85 - 110 "
"	8	"	100 - 135 "
"	6	"	130 - 185 "
"	4	"	150 - 200 "

THE REFERENCES IN COLUMN FOUR SIGNIFY THE LENGTH OF WELD TO BE APPLIED PER ELECTRODE. THUS 10/12 INDICATES THAT ONE No 10 S.W.G ELECTRODE MUST BE DEPOSITED ALONG A LENGTH OF 12 INCHES.

Fig. 177.—Table of Welding Data for Overlap Joints
(*The Quasi-Arc Co.*)

"Quasi-Arc"

W.D 50.

FILLET WELDS

SUGGESTED PROCEDURE AND APPROXIMATE ELECTRODE CONSUMPTION.

The Quasi-Arc Company, Limited,
15 Grosvenor Gardens, Victoria,
London S.W.1

Fillet Leg Length	Welding position and procedure	Run number	Length of run per electrode inches	Electrode consumption per foot of fillet S.W.G.	Number
1/8"		1	10/12	10	1
		1	10/12	10	1
3/16		1	10/7	10	1·7
		1	10/7 or 8/11	10 or 8	1·7 · 1·1
1/4"		1	8/6	8	2
		1	8/6	8	2
3/8"		1 2 & 3	8/9 or 10/6 8/9	8 or 10 and 8	4 2 2·7
		1 2	8/8 8/6	8	3·5
1/2"		1 2 3 4	8/9 or 10/6 8/7 8/6 8/7	8 or 10 and 8	6·7 2 5·4
		1 2 3	8/8 8/6 6/6	8 6	3·5 2
5/8"		1 2 3 & 4 5 & 6	8/9 or 10/6 8/6 8/8 8/7	8 or 10 and 8	9·7 2 8·4
		1 2 3 4 & 5	8/8 8/6 6/6 8/8	8 6	6·5 2
3/4"		1 2 & 3 4 - 7 8 9	8/9 or 10/6 8/9 8/7 8/6 8/7	8 or 10 and 8	13·2 2 11·9
		1 2 3 - 5	8/8 8/6 6/6	8 6	3·5 6

The current range required for each gauge of 'Quasi-Arc' electrode is as follows :-

No. 16 S.W.G.	20 - 35 amps
" 14 "	35 - 45 "
" 12 "	65 - 85 "
" 10 "	85 - 110 "
" 8 "	100 - 135 "
" 6 "	130 - 185 "
" 4 "	150 - 200 "

The references in column four signify the length of weld to be applied per electrode. Thus 10/12 indicates that one No.10. S.W.G. electrode must be deposited along a length of 12 inches.

Fig. 178.—Table of Welding Data for Fillets
(The Quasi-Arc Co.)

easy matter to say which will give the best results on any one particular class of work. There is no doubt that there are many good electrodes now being made, and it is for the user to choose those which, after testing, give the best results when used on his particular class of work.

Dr. J. H. Paterson recently read a paper[1] on this subject before the Institute of Welding, in which he stated—

There is growing up a considerable volume of literature on the various aspects of electric arc welding, with the somewhat unfortunate result that it is becoming increasingly difficult to correlate the work of different investigators. When coated electrodes are used for experimental work the task becomes extremely difficult, as nothing is usually known as to the composition of the coating of the electrodes used. In some cases long and intricate investigations have been carried out with proprietary electrodes, and athough the name of the manufacturer is given in these investigations, they become nearly worthless from a purely scientific standpoint, as the influence of the coating ingredients on the conditions of deposition and on the chemical and mechanical properties of the weld metal is not dealt with. Further than this the results obtained by one investigator cannot be assumed by another worker, as he may be working under a totally different set of conditions unless he uses the same make of electrode.

In order to overcome this difficulty it is proposed to describe herewith a "Standard" electrode in which the composition of the coating and the method of manufacture can be readily repeated in any laboratory. Although there are many hundreds of proprietary brands of electrodes on the market, they all have in common that they produce a certain amount of slag when used. A simple form of coating material of the slag producing type has, therefore, been chosen; and although the electrode made from it has certain drawbacks which make it unsuitable for commercial exploitation it forms a convenient base to which by the addition of various other materials electrodes similar to the well-known types can be produced for experimental purposes. The details of the standard electrode, which at present has only been made in two sizes, are as follows.

[1] Delivered in April, 1935. Extract published by permission of the Institute of Welding.

Core Wire

A mild steel wire of the following chemical composition is used—

Carbon	0·11—0·13%
Manganese	0·35—0·45%
Sulphur and Phosphorus . .	0·04% each max.
Silicon	Trace.

Coating

Magnetic oxide of iron (98% Fe_3O_4)	70 parts
Precipitated Silica (99% SiO_2)	30 parts
	100 parts

In both cases the material is used in the form of a fine powder which will pass a sieve of 120 meshes to the inch.

Binder

Silicate of soda is used, the ratio of Na_2O to SiO_2 being 1 : 2. This is mixed with water to produce a solution having a specific gravity of 1,250 at 15° C.

To make the coating, the mixed powders are thoroughly incorporated with the silicate of soda in the proportion of 500 parts by weight to 250 parts by weight of the silicate solution. This is placed in a vertical brass dipping tube of about 1·5 inches diameter and 20 inches high and the electrode rods immersed and slowly withdrawn. After the excess material has dripped off, the electrode is hung up to dry for 4 hours and a second and then a third coat applied in the same manner. After the third coat the rods are thoroughly air dried and then heated at a temperature of 105° C. for 4 hours. The finished rods, if carefully made, should have a concentric coat, but they will not be uniform in thickness. To overcome this difficulty the rods are then carefully ground down till the external diameters are as follows—

No. 8 s.w.g. Core Wire (0·160 in. dia.)—0·235 in.
No. 10 s.w.g. „ „ (0·128 in. dia.)—0·205 in.

The weight of the coating on the 8 gauge rod should then be 1·24 grs. per inch of coated rod and the weight on the gauge rod 1·07 grs. per inch. The softening point of the coating mixture is approximately 1,100° C. so that it is of the high melting point order. For comparative purposes, it might be

noted that the corresponding temperature for a common form of blue asbestos powder made into a coating with silicate of soda is approximately 800° C. and that most of the commercial coatings used fall within these extremes.

The specific gravity of the slag produced when the electrode is melted is 4·27 and it might be again noted that commercial coatings produce slags with a specific gravity lying between 3·6 and 4·35.

The data below, which actually apply to the Quasi-Arc Co.'s products, may be taken as typical.

APPROXIMATE WEIGHT OF 100 ELECTRODES

Electrodes	Lb.	Kg.
16 S.W.G. 9 in. .	1·125	0·51
14 ,, 12 in. .	2·67	1·21
12 ,, 18 in. .	5·25	2·38
10 ,, 18 in. .	8·00	3·63
8 ,, 18 in. .	12·00	5·45
6 ,, 18 in. .	17·00	7·75
4 ,, 18 in. .	24·00	10·90

APPROXIMATE EQUIVALENTS OF STANDARD WIRE GAUGE

S.W.G.	DIAMETER		Nearest fraction of an inch
	In.	mm.	
16	0·064	1·60	1/16
14	0·080	2·03	5/64
12	0·104	2·64	3/32
10	0·128	3·25	1/8
8	0·160	4·06	5/32
6	0·192	4·88	3/16
4	0·232	5·89	15/64

EYE PROTECTION

Very considerable advance has been made in regard to the best protection that can be given to the eye by the

use of screens, goggles, etc., but, unfortunately, advantage is not being taken either by welders or employers of the available information as to the best form of protection which can be afforded. Welders are advised to use screens or goggles which have been recommended by reputable firms, and which they themselves have tested to ensure that they are suitable for their own particular eyes. In addition to the information given in the earlier pages of the book the following extract from *Electric Welding*[1] will be found useful—

Arc Eye. The rays emitted by the electric arc in welding contain ultra violet rays and infra-red rays which although not dangerous are painful to the eyes. This discomfort is caused by the extreme intensity of these rays and in the fact that the human eye cannot withstand exposure to them without having its very delicate nerves and membranes injured.

When electric arc welding was first practised, glasses were used by the welders to reduce the glare and to enable them to see the arc, and the weld metal being deposited. In consequence smoked or tinted glasses were found to be satisfactory until welders complained of eye trouble. Investigations into this revealed the harmful effect of these invisible rays, and steps were taken to produce glasses which had the property of absorbing them and preventing their access to the eye.

Screen glasses, therefore, have to be capable of carrying out two distinct functions. They must render the welder immune from the effects of ultra violet and infra-red rays, and they must reduce the glare from the arc and make the work distinguishable.

As a result of the scientific investigations, a combination glass was evolved which utilized these requirements and is entirely successful in preventing arc eye trouble.

Although the use of a welder's screen containing these special glasses renders the welder safe from the direct rays of the arc, eye trouble can still be obtained from indirect flashes made by welders working in the neighbourhood, which may be viewed direct or reflected from bright objects such as polished metal or light reflecting walls.

The symptoms of "arc eye" are inflammation of the eyes,

[1] By permission of the Quasi-Arc Co. Ltd.

with a feeling that they are full of sand (conjunctivitis) and a general desire to avoid light.

Bathing the eyes with the undermentioned lotion, using an eye bath, is found to give the quickest and safest remedy.

Lotion to be Used for "Arc Eye"

Boracic Acid . . .	210 grains (14 g.)
Laurel Water . . .	½ fluid oz. (14·78 c.c.)
Rose Water . . .	8 fluid oz. (236·56 c.c.)
Glycerine . . .	1/5th fluid oz. (6 c.c.)
Distilled Water . .	12 fluid oz. (350 c.c.)

It is thus obvious that to prevent welders suffering "arc eye," special screen glasses such as those prepared by the Quasi-Arc Co. must be used, and bright objects and reflecting surfaces in or around a welding shop must be removed. In addition, the fitting of screens round the welders will be found to be of great advantage in the elimination of direct flashes.

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